MODERN ILLUMINANTS

AND

ILLUMINATING ENGINEERING

BY

LEON GASTER AND J. S. DOW

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TO

PROFESSOR SILVANUS P. THOMPSON, D.Sc., F.R.S.

FIRST PRESIDENT OF THE ILLUMINATING ENGINEERING SOCIETY (FROM 1909 TO 1914)

IN RECOGNITION OF VALUABLE SERVICES RENDERED

TO THE CAUSE OF GOOD LIGHTING

THIS BOOK IS DEDICATED

PREFACE.

SINCE the issue of *The Illuminating Engineer* in this country in 1908, and the subsequent formation of the Illuminating Engineering Society, the subject of Illumination has received much attention.

At that time anyone wishing to be kept informed of progress in lighting by gas, oil, acetylene, or electricity had to study a variety of journals dealing with these respective illuminants, and it was difficult to find any book treating all of them in a thorough and impartial manner. Papers on photometry appeared at intervals in the transactions of various scientific and engineering societies. Information regarding the effect of light on the eye had to be sought in journals devoted to physiological and ophthalmological matters. Moreover, while a certain amount had been written on the manufacture of lamps and lighting appliances, the *practical applications of light* had been very little discussed.

About eight years ago it was suggested to one of the authors that he should write a book on Illumination. But it seemed better to defer doing so until the subject had been more completely discussed and had become better understood. Now the Illuminating Engineering Societies in this country and in the United States have provided platforms for such impartial discussion, and during the last few years a growing number of articles on lighting have appeared in the technical press. Although there is still much to be learned, enough has already been done to show that the subject is capable of impartial treatment.

It therefore seemed to us that a book dealing generally with

Illumination would be welcome at the present moment. We have treated the subject on broad general lines. The initial portion of the book is devoted mainly to the various illuminants, the central portion to photometry and the effect of light on the eye, and the last part to practical lighting problems. Our aim has been to bring together matter not usually available in a single volume, and the subject has been treated in a manner somewhat different from that adopted in previous text-books on Illumination.

Naturally, the decision to discuss the subject on these broad lines forbade our entering deeply into details. The various branches of Illumination are advancing so rapidly that it is only possible to indicate roughly present knowledge and experience, and it is evident that in years to come some revision will be needed. Text-books dealing with special sections of illuminating engineering are already beginning to make their appearance, and will serve to supplement our treatment in a more detailed manner.

A feature to which we should like to draw attention is the large number of references, which will enable readers to refer to the original papers for fuller information. We have allotted chapters to well-defined divisions of the subject, and have included a summary of contents at the head of each. This arrangement, together with the index at the end of the volume, should enable readers to look up information on specific points without much difficulty. We have also added a list of the more important books on lighting that have been published during the last five years, together with a few of earlier date which seemed particularly interesting.

We are fortunate in having secured an exceptional variety of illustrations, many of which have appeared in *The Illuminating Engineer*, and are reproduced by the courtesy of the Illuminating Engineering Publishing Co., Ltd. We may mention that a large proportion of the photographs were taken by artificial light; for this work we are indebted mainly to our friend Mr V. H. Mackinney.

We have also to express our thanks for the assistance freely given by many firms whose lighting appliances are mentioned in this work. And, finally, we should like to make special acknowledgment of the help of several gentlemen—among whom we may mention particularly Mr J. G. Clark, Mr C. C. Paterson, Mr A. P. Trotter, and Professor Silvanus P. Thompson—who have read portions of the proofs and given much valuable advice.

LEON GASTER.
J. S. DOW.

January 1915.

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To attempt a history of artificial lighting would be an undertaking far beyond the scope of this volume. Several valuable sources of information on the subject are already available. M. Allemagne,[1] for example, in a fully illustrated historical treatise, has already provided a record of the development of artificial lighting among the more civilised nations of the past and in the middle ages. Much has also been written on the incomparably more rapid progress of the last few years. Yet it may be surmised that the most interesting history of illumination is now in the making; and that recent developments, remarkable as they have been, will form but the prelude to even more striking progress in the future.

The very earliest conceptions of light seem to have been connected with the study of the heavenly bodies. In this

[1] Allemagne, *Histoire du Luminaire* (Alphonse Picard, Paris, 1891).

association of ideas many of our modern impressions have their root. Dr M. Gaster,[1] in a striking series of articles in *The Illuminating Engineer*, has shown how the earliest religions sprang from the worship of the sun, moon and fire. Ra—the Sun—was one of the chief gods of Egypt, and the deities of the Assyrians and Babylonians, and even of the ancient Greeks, seem to be merely local manifestations of the same idea. It was a natural consequence of the conditions of those times that light should become an object of worship. We, living in an age of abundant light, find it hard to realise the consequences of its scarcity among primitive peoples. We cannot readily imagine the sense of insecurity and terror which seized men with the setting of the sun, when darkness covered the earth, and all the powers of evil were let loose. But as we seek to picture this state of mind we cease to wonder that evil came to be associated with darkness, while light was regarded as something holy and sacred.

This association of darkness with evil, error and confusion permeates our ideas and phrases even to-day. It survives in such expressions as "The Prince of Darkness," "Dark deeds," "Lighten our darkness, we beseech Thee," etc. An excellent illustration of the same symbolism is afforded by Maeterlinck's delightful and poetical play, *The Blue Bird*, which was recently performed in London. Here Light appears as the constant and faithful friend of man, and it is in the Palace of Night, into which Light cannot enter, that all evil things—ghosts, sicknesses, wars, and terrors—have their dwelling.

Dr Gaster has also pointed out how light, from being an object of worship, soon came to play an important part in religious ceremonial. The sacred lamps in the temples of ancient Rome, the fire kept burning even to-day on the hearth of the devout Brahmin, the candles which shed their light on the altars of modern churches are all illustrations of the same form of worship. It will be observed, too, that the uses to which light was put in early ages all served to emphasise its rarity and sacred nature. Apart from its use in religious ceremonial, the display of light has always been associated with special festivities and occasions of great national rejoicing. We learn, for example, that this was the custom of the ancient Egyptians on feast-days, that the Emperor Constantine caused the whole city of Constantinople to be illuminated with wax candles on Christmas

[1] *Illum. Eng.*, London, vol. ii., 1909, pp. 371, 462, 520, 586, 660, 731, 804.

Eve, and that on birthdays the houses of the Romans were sometimes decorated with lamps attached by chains to the roof.

As time went on artificial lighting became a more familiar process, although for long only available in the homes of the rich and sparingly used there. Naturally, it was only in comparatively civilised countries that much progress was made. Indeed, so significant is the respect in which light was held among all nations, that Dr Gaster has suggested that proficiency in the use of artificial light might well be regarded as a criterion of the degree of civilisation to which a people has attained.

The Earliest Illuminants—Wood Fires and Pine Torches.

The earliest source of light, it would appear—the wood fire, was kindled both for light and warmth. Naturally, such an unsteady and flickering source was not of great help in prolonging the hours of labour. In the open it served as a protection against wild beasts. On the hearth it united the family circle when the day's work was done. Resinous wood, pine splinters, and the like were used as torches by the Romans, and even in the time of Homer. Von Benesch, in his valuable and unique work on *Illumination in the Middle Ages*, has described how such pine splinters were habitually burned for light by the peasants of that period, and are so used in some remote districts even to day.[1]

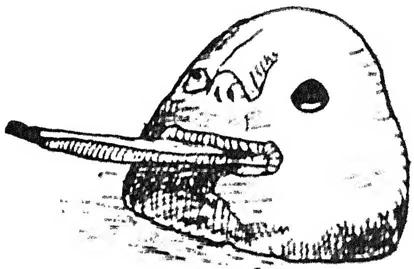


Fig. 1.—Old form of skull holder for splinters (Niemann and du Bois.)

Sometimes the methods of lighting by this means were even more primitive, pieces of wood being merely kindled and thrown into pans or niches in the wall. Drs Niemann and du Bois[2] mention that at an earlier period it was often the custom for one of the younger servants to hold a splinter in each hand. Occasionally the torch was held in the mouth so as to leave the hands free. This custom is exemplified in the rather gruesome skull-shaped holder shown in fig. 1.

[1] *Das Beleuchtungswesen vom Mittelalter bis zur Mitte des XIX. Jahrhunderts aus Oesterreich-Ungarn* (A. Schroll & Co., Vienna, 1905).

[2] "Zur Geschichte des Beleuchtungswesens," *Jour. f. Gasbel.*, 14th December 1907; 1908, pp. 341, 970.

The authors had recently the good fortune to come across a collection of old lamps, that of Mr J. W. Johnston of Hendon which contained quite a number of specimens of these kindled splinter devices. By the courtesy of Mr Johnston this collection

FIG. 2.—Group of rush-lights, "peermen," tinder-boxes, and stone lamp.
(14 specimens from Mr Johnston's collection.)

was described in *The Illuminating Engineer*, and the above illustration is one of those occurring in this article.[1] In Scotland these splints, which until recently were in quite common use, were termed "puirmen" or "peermen." The name originated from the fact that poor men, vagrants (or "gaberlunzies," as

[1] *Illum. Eng.*, London, August and September, vol. v., 1912, pp. 387, 425.

they were called in Scotland), used to turn an honest penny by collecting the splinters and selling them in bundles. Some of the clips shown in the illustration were intended for splinters, others from Wales and Ireland were devised for rush lights.

ANCIENT LAMPS USING OILS AND FATS.

The next step was the separation of the resinous and pitchy materials, which were burned in open braziers, and ere long this was followed by the use of vegetable and animal oils and fats.

Böhm[1] recalls that in Memphis, Thebes, and Nineveh festivals

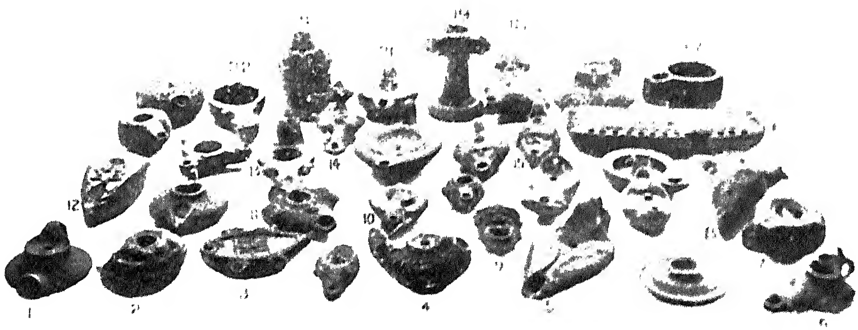


FIG. 3. Group of Egyptian pottery and bronze lamps.
(26 specimens from Mr Johnston's collection.)

were celebrated by the use of large stone vases filled with liquid fat to the weight of 100 pounds or more.

Primitive lamps of stone, clay, or terra cotta date back to quite prehistoric times, and in Mr Johnston's collection referred to above, there are several hundreds of such lamps, some of them dating from many years B.C. In fig. 3 a few of them are seen.

In many instances we see traces of distinctly artistic design although as illuminants such lamps must have given but a feeble and flickering light. The design of the later Etruscan, Roman and Greek lamps of this kind was more elaborate, the material being frequently brass or bronze and the workmanship exquisite. In a most remarkable book published in Paris in 1719[2] (also in

[1] "History of Illumination up to the Incandescent Mantle," *Illum. Eng.*, London, vol i., 1907, p. 106.

[2] *L'Antiquité expliquée et représentée en figures*, by Dom Bernard de Montfaucon, Paris, 1719.

possession of Mr Johnston), illustrations of a considerable number of them are given. In some cases very grotesque and fantastic shapes are adopted. For example, the handle is made in the shape of a swan's neck, or the lamps in the form of elephants, snails, and curious birds and beasts, often carved with considerable amount of skill and ingenuity.

Looking back over the early Egyptian lamps shown in fig. 3, the chief thing that strikes one is the enormous period of time over which the primitive and crude design of these early oil lamps remained substantially the same. Contrast the conservatism of these hundreds and thousands of years with the marvellous progress in lighting during the last decade!

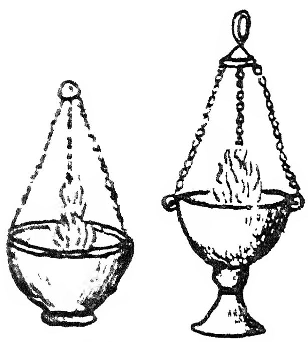


Fig. 4.—Showing development of hanging lamps from eating- and drinking-vessels.

The evolution of many of these early lamps is most interesting to the lighting engineer. For example, fig. 4 shows the development of hanging lamps from eating- and drinking-vessels. It can also be shown that some modern fixtures are derived from a tree, the lamps hanging on chains and metal limbs just as the fruit hangs on the branches. For these two interesting sketches we are again indebted to the researches of Niemann and du Bois (*loc. cit.*).

The use of wicks resting in vessels containing fats and oil led naturally to the idea of a rush soaked in grease, which was really a primitive form of candle. It appears that such lights were known to the Romans, who used reeds dipped in oil. We see here something akin to the humble rush-light, which formed the sole illuminant of the poor in some districts within living memory.

Wax-lights and Candles.

The next improvement of note was the manufacture of candles—a natural development from the old rush-light. Böhm (*loc. cit.*) relates that the Romans had already learned to distinguish between the uses of wax and tallow; while the Phœnicians bleached wax and constructed serviceable candles, which were introduced into Constantinople about the fourth century. Yet

in its essential elements the candle seems to have remained practically the same until last century.

Right through the middle ages, and indeed until the discovery of petroleum in large quantities, candles remained almost the only method of lighting within the range of people of average means. The poor man was perforce content with a few lights of inferior quality. On the altars in the churches and in the salons of the rich the finest wax candles might be seen, but chandeliers carrying an immense number had to be used in order to secure a reasonably bright illumination. Offerings to the Church in the middle ages very frequently took the form of elaborate and richly ornamented chandeliers.

Many amusing records are to be found of the esteem in which only a single candle was formerly held. It was a mark of nobility to be preceded by a candle in going to bed, and M. Allemagne relates how when, in 1694, the Dauphin took the Marquis de Passe prisoner, he considered he was granting quite an exceptional privilege in allowing him a candle when retiring for the night! The same author reproduces an old print showing Michael Angelo painting feverishly at a masterpiece with a candle fixed in the brim of his hat.

It must be remembered too that the fine wax candle was only within the means of the rich. For example, the *Evening News* recalls the typical bill of the early Victorian inn, which, "for a gentleman who called himself a gentleman," began with the item, "wax-lights, 5/." The poor man was, perforce, content with the tallow dip.

A writer in *The Illuminating Engineer* has traced the early struggles of the Guilds of Wax and Tallow Chandlers in England during the fourteenth and fifteenth centuries.[1] Niemann and du Bois mention that Guilds of Candlemakers were formed in Hamburg in 1375, and in Paris even as early as 1061. In London the monopoly of candlemaking originally rested with the Guild of Wax Chandlers. It is interesting to observe that the guild induced the Mayor, Aldermen, and Sheriffs of London to establish a strict specification for candles in which their constituents and details of manufacture were minutely described; anyone manufacturing and selling candles which were out of accordance therewith was liable to heavy penalties.

A little later, however, we find this guild struggling desperately against the introduction of tallow candles, the

[1] *Illum. Eng.*, London, vol. ii., 1909, p. 734; vol. iii., 1910, p. 13.

[illegible] costliness of tallow and wax being at that time in the [illegible] 15. The tallow chandlers in their turn eventually gained the upper hand and likewise aimed at the standardisa[illegible] their products, only to drift into the same obstructive [illegible] towards the next illuminant, oil, which had now begun [illegible] its appearance. This little piece of history is instructive [illegible] illustration of the opposition invariably offered to [illegible] by old-established concerns and also as a precedent [illegible] a standard specification of illuminants.

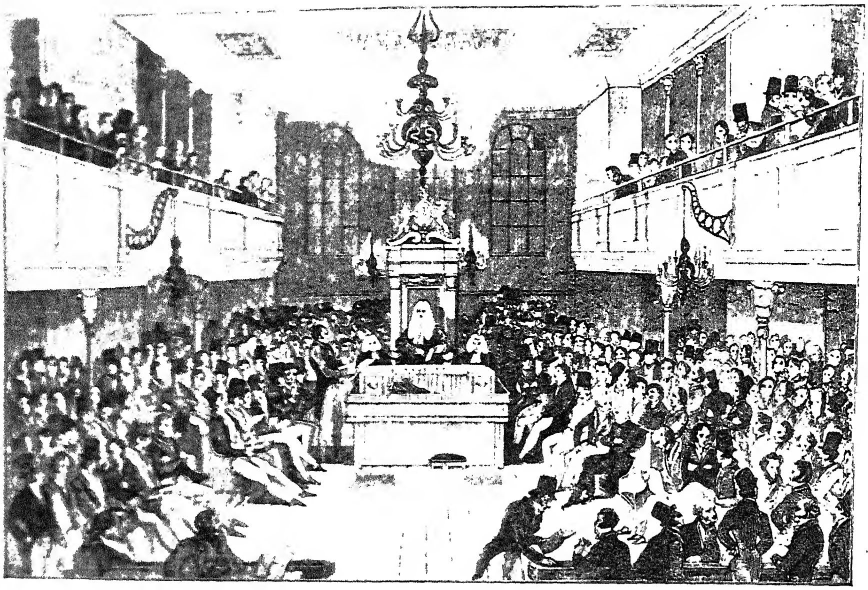


FIG. 5.—Interior of the House of Commons in 1834.
(Thornbury, *Old and New London*, vol. iii. p. 511.)

It is not unnatural, seeing that candles retained their supremacy as the sole effective means of illumination for so long, that in many quarters they should be still regarded as the only appropriate method of lighting, sanctioned by custom and tradition and not to be displaced by modern methods however convenient.

Perhaps one of the best examples of the reluctant consent to the adoption of gas in place of candles is the House of Commons. Fig. 5 is a reproduction of an old print showing this method of illumination in 1834.

When a few years later Dr D. B. Reid suggested the introduc-

tion of gas, the categorical answer he received from Sir Benjamin Stephenson and the Earl of Bessborough was, "Do what you like for the acoustics and ventilation, but take it as a fixed and settled point that wax candles remain."[1]

Yet the progress of the age renders such changes merely a question of time. Commenting on the recent conversion of Caen Wood House, the residence of the Earls of Mansfield, which, until a few years ago, was lighted exclusively by candles, the *Evening News* remarks:

"To a twentieth-century babe the miracle of the electric button is the normal and unremarkable method of producing light, while the candle is a mild-tempered firework—a festal-light device for lighting birthday cakes."

Oil Lamps and Lanterns.

The step from candles and vessels containing melted fat to the oil lamp proper was a very gradual one. Such lamps, like candles, were applied to church lighting and ceremonial at a very early date. As a means of illuminating surroundings these lamps were feeble indeed, but as works of art they were often magnificent. Many of the early Carthaginian and Roman lamps excelled in this way, and the Venetian lamps of later days showed exquisite workmanship. The loving care devoted to the embellishment of these old lamps presents a remarkable contrast with much of the business-like and purely utilitarian design of modern fixtures and illuminants.

In these lamps animal and vegetable oils were mainly used, and it was not until the middle of the nineteenth century, after the discovery of petroleum in large quantities in America, that the oil lamp proper was developed. Yet important steps had been taken from time to time in the development of the oil lamp, notably the substitution by Argand of the round wick for the flat one previously employed. This enabled the air to have more perfect access to the flame and led to a substantial increase in the light. The introduction of the glass chimney, also ascribed to Argand, was another great step, and it is probable that the work of this scientist, and that of Carcel and others towards the end of the eighteenth century, did much to pave the way for the success of the later forms of oil lamps.

In 1836 the Moderator form of oil lamp, combining many of

[1] *Illum. Eng.*, London, vol. ii., 1909, p. 665.

these improvements was introduced and widely used. Other improvements in detail followed, until eventually the discovery of petroleum led to the popularisation of this means of lighting on a large scale.

The History of Street Lighting.

By the feeble light of candles and oil lamps street illumination, in its proper sense, could hardly be attempted. All that was possible was to indicate the course of the street by "beacon-lighting" methods, *i.e.* by small lamps at frequent intervals, which served to shed a feeble glimmer over the roadway, but barely sufficed to show where the pavement ended and where the road began. In old prints of London life the "link-boy" with his torch was a prominent feature, and in the dense fogs which a few years ago commonly afflicted the metropolis his services were still in occasional demand.

Regular lighting in London appears to have been attempted at a very early period. It is most interesting to trace, as a correspondent in *The Illuminating Engineer* (London) has done,[1] the development of public lighting in this city, and to observe how the duty, originally imposed on private householders, gradually passed into the hands of municipal authorities.

We, in this age of abundant illumination, can hardly credit the insecurity of the streets in those early days, when "it was a common practice in this city that a hundred or more in a company, young and old, would make nightly invasions upon houses of the wealthy to the intent to rob them, and that when night was come no man durst adventure to walk in the streets."

The first attempts at regular street lighting in London appears to date from 1415, when Sir Henry Burton, then Lord Mayor of London, ordered all householders to hang out lanterns in the winter evenings between All-Hallows and Candlemas. This practice they were obliged to follow, on pains and penalties, for upwards of three hundred years. The watchman with his long coat and halberd passed along the street crying:

> "A light here, maids, hang out your lights,
> And see your horns be clear and bright
> That so your candle clear may shine,
> Continuing from six to nine,
> That honest men may walk along—
> May see to pass safe without wrong."

[1] *Illum. Eng.*, London, vol. ii., 1909, pp. 87, 272.

In 1694 an ingenious man named Edward Heming obtained letters patent giving him the exclusive right, at a moderate remuneration, of placing a light opposite every tenth door. His contemporaries, however, attacked him furiously, and the license was withdrawn in 1716. In that year it was directed that every householder whose house fronted a street and was rented at £10 should be obliged, under a penalty of one shilling, to hang out a light during every dark night from September 29th to March 25th, and to keep these lights burning from between the hours of six and eleven.

After 1736 it was decided to take the contracting for this lighting out of private hands, and the organised service passed into the hands of the Common Council of Ward, the Aldermen Deputy and Common Councilmen of each ward being empowered to contract for the illumination of that locality and to levy a rate for the purpose. The business of lighting came at last to be placed in the hands of the Commissioners of Sewers. It is interesting to observe how in England (as in France) lighting, the functions of cleaning the roads, and sanitary matters came to be associated at this early period.

In an old work by Professor J. Beckmann of Göttingen University, entitled *A History of Inventions, Discoveries, and Origins*, some interesting details of the lighting of London are given. The account concludes with the words:

> "At present (1786) the lamps of London are all of crystal glass; each is furnished with three wicks, and they are affixed to posts. They are lighted every day in the year at sunset. Oxford Street alone is said to contain more lamps than all Paris. . . . The roads even seven or eight miles round London are lighted by such lamps, and, as these roads are very numerous, the lamps, seen from a little distance, have a most beautiful and noble effect."

The history of street lighting in Paris during this period was not unlike that in London. The subject has been very fully treated in Allemagne's excellent work (*loc. cit.*), and likewise in M. Defrance's *Histoire de l'Éclairage des Rues de Paris*.

As early as 1367 Charles V. issued regulations regarding the placing of lamps at stated intervals in the streets, and in 1407 the Prefect of Police, whose duty it appears to have been at a very early time to attend to public lighting, ordered the hanging out of lanterns by householders as a means of mitigating the disorderly character of the streets.

It was, however, not until 1666, in the reign of Louis XIV., that a marked advance in public lighting was made, largely at the instance of La Reynie, the Lieutenant of Police, whose motto "Netteté, clarté, sûreté," was an epigrammatic summary of the objects of street lighting of that day. King Louis, in commemoration of the resolve to improve the lighting, taken by the Conseil de Police in 1666, caused a special medal to be struck, and in 1669 yet another. La Reynie caused as many as 2726 lanterns to be hung in the streets, and the period of burning each night was lengthened. It was customary to reduce the time of lighting in summer, and the merchants of that time presented an appeal asking that all-night lighting should be established all the year round. (Curiously enough, a very similar request has recently received support from the Prefect of Police in Paris, who urges the benefit of such a provision as a means of checking the crime and depredations of the apaches of to-day.)

The improved conditions of lighting, however, seem to have given rise to great popular enthusiasm, and were considered a remarkable advance in Europe at that time. The progress continued, and in 1729 as many as 5772 lanterns were in use. Some of the old prints representing them slung on ropes across the street are very suggestive of the most modern methods of suspending arc lamps in use to-day. These lanterns were attended to regularly under the supervision of the police. The occasional renewal of mantles or arc-lamp carbons in the lamps of to-day is sometimes considered troublesome; but this appears a trifle when it is noted that the wicks of these old lamps required cutting *hour by hour* to keep the flame burning.

In 1745 oil lamps with reflectors above the flames came to be introduced, and in 1766 M. de Sartine, the Lieutenant of Police, offered a prize of 6000 livres for the best form of lamp for street lighting. Lavoisier, the great chemist and physicist, Bourgeois, and others occupied themselves with this matter. The former published a most elaborate physical investigation into the properties of such reflectors and the best method of shaping them so as to distribute the light efficiently—quite in the manner of the best illuminating apparatus of the present time.

In fig. 6 we reproduce an old French print illustrating the interest excited among the citizens of Paris by oil lamps

suspended over the roadway (just as many gas and electric lamps are to-day).

We now reach the next stage in public lighting, the introduction of gas. The course of events during the preceding years seems to have been very similar in the chief European countries. Niemann and du Bois (*loc. cit.*) mention that in Germany similar obligations as regards hanging out lamps were imposed on householders, and in that country, just as

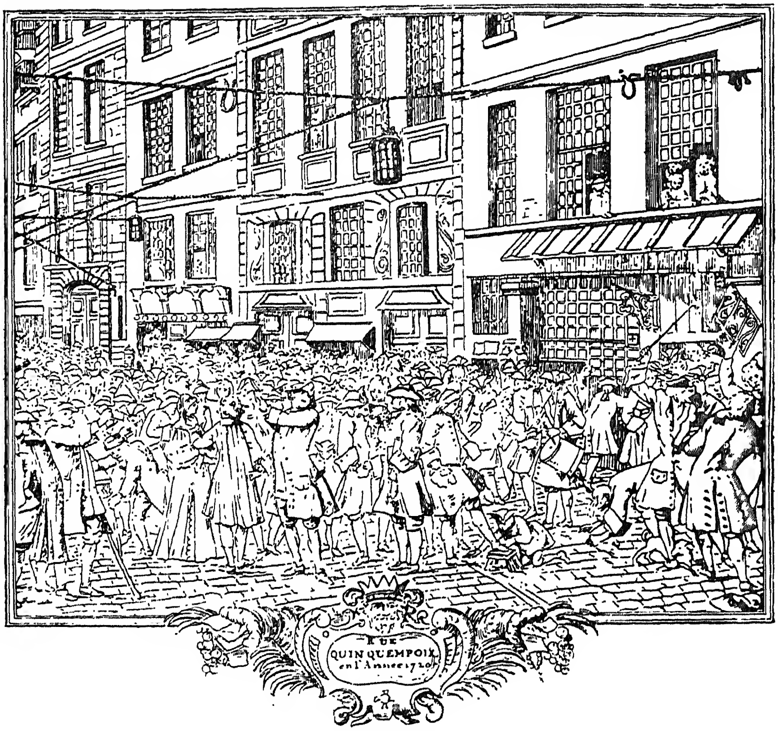


FIG. 6.—The lanterns of the Rue Quincampoix in 1720.

in Paris and London, street lighting gradually became a public matter instead of a private obligation. We may note, however, as of special interest, the appointment in Berlin of a certain Matthias Hasse in 1682, with the title of "Inspektor der Stadtleuchten."

The author of the *History of Inventions and Discoveries* states that in 1786 systematic street lighting had been adopted in Vienna, Amsterdam, Philadelphia, Madrid, and other cities —Rome, however, being still an exception.

THE COMING OF GAS LIGHTING.

There seem to have been quite a number of independent attempts to produce illuminating gas at the end of the eighteenth century. Clayton, Lord Dundonald, and William Murdoch in Great Britain, Becher in Munich, and Le Bon in France all occupied themselves with the matter.

The credit for bringing the invention to a practical stage is largely due to Winzler (or, as he is known in this country, Winsor) a Moravian, who investigated Le Bon's work and eventually came to England and founded the Chartered Company. Previous to this, William Murdoch, who has been aptly described as "the father of gas lighting," started making gas at his factory in Soho, the whole façade of which was brilliantly illuminated in honour of the Peace of Amiens in 1802. The Lyceum in the Strand was illuminated in 1803, and the whole of Pall Mall in 1809. Subsequently the Chartered Company secured rights for the whole of England, and gas-works were erected at Birmingham, Hull, and other towns.

Progress, however, was exceedingly slow at the commencement. Not only were the promoters faced by exceptional pioneering technical difficulties, but they were hampered by an almost incredible amount of misunderstanding, and by the opposition of formidable industries.[1]

The introduction of gas was keenly contested by the dealers in oil and tallow—just as the introduction of tallow candles had been opposed by the wax chandlers centuries before—who drew dismal pictures of the impending ruin to their industry. Yet the makers of oil lamps and candles might have spared themselves alarm. Mr Dumoncel, in his work on electric lighting, remarks:

> "The producers of lamp oil were at this time struck with dismay, for in this discovery they saw the ruin of their industry. But they soon found that, contrary to their expectation, the consumption of lamp oil increased with the development of gas illumination. It could not, indeed, be otherwise, for gas illumination, by accustoming people to a brighter light, was bound to lead to an increase in the number of lamps for private illumination."

This experience, it may be added, has been repeatedly confirmed in more recent times. The development of each new method of lighting has not hindered but helped the growth

[1] See a lecture on "The History of Gas Lighting," by W. J. A. Liberty, *Illum. Eng.*, London, April 1913.

of others by raising the standard of illumination; so that to-day not only gas, oil, and candles, but electricity, acetylene, petrol-air, and many other systems of lighting have all a useful sphere of action, and are still finding new applications.

For a long time the progress of the industry was hampered by the struggles between competing gas companies, several of whom often operated over the same area. Gradually, however, with the assistance of Parliament, this destructive warfare was terminated and conditions came to approach more nearly those of to-day, when two vast companies, the Gaslight and Coke and the South Metropolitan, in their respective areas control the lighting of the greater part of London. Through the efforts of these early pioneers the public was gradually educated to appreciate the benefits of illumination supplied from a distance, and there can be no doubt but that these initial difficulties did much to smooth the way for electric lighting when it eventually arrived.

While the very earliest practical gas lighting appears to have been initiated in England, progress on the Continent was also rapid. Böhm states that Unter den Linden in Berlin was first illuminated by gas in 1827, Dresden in 1828, and Leipsic in 1837; by 1850 the majority of the larger German towns had installed gas.

In the same way experiments were begun in Paris about 1817, and during 1820 to 1840 there were as many as six different companies at work. In 1855 these were fused into a single concern, the Compagnie Parisienne d'Éclairage. By about 1850, as in Germany, most of the provincial towns in France had adopted gas lighting.

The Coming of the Electric Arc Light.

The invention of the electric arc is generally dated from the famous experiments of Sir Humphrey Davy early in the last century. Naturally, this was merely a feeble forerunner of the arc lamp as we understand it to-day, the current being derived from a series of primary batteries and the arc provided between two sticks of carbon. Few things indeed are more remarkable than the devising of such a powerful source as the arc lamp while methods of generating electricity were so very primitive. Lamps provided with mechanism were stated to have been devised by Thos. Wright of London in 1845. Foucault somewhat earlier had devised a simple hand feed-lamp, and even used it for

microscope projections. When, shortly after this, lamps were exhibited at the Place de la Concorde in Paris the current was still derived from a voltaic pile. The public, however, were amazed at so powerful a light, and the fanciful idea of a city illuminated by a single lamp of immense candle-power suspended in the air—a miniature sun, in fact—was put forward as a possibility in the near future.

The use of arc lighting for regular public service can scarcely be said to have existed earlier than the 'seventies; and the real arrival of electric lighting, from an industrial standpoint, is often dated from the Paris Exhibition of 1881. The long period before this date was largely occupied in devising appropriate methods of generating electricity in commercial quantities.

Yet there are records of the occasional use of electric lighting much earlier than this. Thus Defrance (*loc. cit.*) recalls that magneto-electrically generated current was first applied to lighting in France in 1859, and in 1867 there were thirty-two lamps in use in the Tuileries gardens in Paris. It is also stated that the first trial of electricity for lighthouse illumination took place at Dungeness, at Faraday's suggestion, in 1857; and that the skating scene in Meyerbeer's opera *The Prophet* was illuminated by electric light at the Paris Opera House as far back as 1846.

Electric glow-lamps were introduced about 1879, the credit for this discovery being given to Swan in England and Edison in the United States. It appears, however, that although these were the first practical examples of lamps of this kind, and the progress in electric incandescent lighting may be said to date from their exhibition, there are on record some remarkably early attempts in this direction. Drysdale,[1] for example, states that filament lamps of a kind were made by de Moleyns in 1841 and King in 1845; and Mantica, in his work on electric lighting, also reproduces an old print in which de Changy, a resident at Brussels, is seen showing the application of an incandescent lamp in collieries, about the year 1850.

In England a great impetus was given to electric lighting by the famous exhibition held at the Crystal Palace in 1882. In 1880 practical experiments in street lighting by arc lamps were being made on the Thames Embankment. By 1882 we find that electric incandescent lamps had already found their way into several notable spots in London, such as the Savoy Theatre,

[1] *Illum. Eng.*, London, vol. i., 1908, p. 295.

the British Museum Library Reading-room, the Editing Office of the *Times,* and the Mansion House. Gatti's restaurant in the Strand was among the first in London to adopt the system. The plant used for this restaurant was subsequently extended to meet the demands of outsiders, and the company formed to carry on this business became the basis of the Charing Cross Electricity Supply Co. In 1881 experiments in the application of electric lamps in collieries had already begun, and in 1884 we find an account of its experimental use in trains.

The advent of electric arcs and incandescent lamps naturally created a great impression. Even the non-technical could hardly fail to perceive that a new era in lighting had begun. Arc lighting soon came to be very habitually used for street lighting, being incomparably the most powerful method of illumination then available. Once again the older established illuminant, gas, seemed to be threatened by extinction. But this caused those interested in gas lighting to make more vigorous efforts, and led to a revolution quite as remarkable in its way as the coming of the electric light.

The Incandescent Gas Mantle.

This rejuvenation of gas lighting occurred through the incandescent mantle exhibited by Auer von Welsbach in 1883.

Although the novelty attracted much attention, it was at first found that mantles did not compare very favourably with the customary flat-flame burners. The early mantles disintegrated rapidly and lost their illuminating value, and it was only the perseverance and brilliant research of Welsbach during the next few years that made the mantle an industrial success.

The necessity for a period of repose while the new method of lighting was being developed and the industry was preparing to accommodate itself to the novel conditions, is shown by the fact that more than ten years elapsed before incandescent gas lighting made any appreciable headway for street lighting. We find that trials in this direction were being carried out in Paris in 1894, and in Hamburg, Wiesbaden, Budapest, and other Continental towns about the same time. By this time Ipswich and Winchester were making experiments in England; while Liverpool, Swansea, Dublin, and other large cities had used it by 1896. In 1900 we find that other cities, including Birmingham, Glasgow, and many of the southern suburbs in London, had followed suit.

THE OPENING OF THE TWENTIETH CENTURY.

The new century opened with a burst of activity surpassing that of twenty years earlier. Not only has actual progress been most remarkable, but the *rate of progress* in artificial illumination has been marvellously accelerated.

In gas lighting a remarkable advance has been made in the introduction of the inverted mantle. Before the display at the Earl's Court Exhibition in 1904, inverted mantles were scarcely known to the general public; indeed there were at that time many experts in gas lighting who seriously doubted the practical success of this invention. Yet to-day there seems a probability that inverted mantles may entirely replace the upright type, and indeed in certain fields they may almost be said to have already done so. Such mantles, besides having marked advantages as regards distribution of light and durability, enable lamps of a remarkable range of candle-power to be obtained; the smallest types are stated to consume less than one cubic foot of gas per hour and to yield up to 20 c.p.; the powerful street-lighting units, on the other hand, are credited with as much as 4000. What a contrast with the first gas lamps introduced to light Pall Mall in 1810, which were stated by the experts of that time to give a light equivalent to three candles, but which nevertheless were considered immeasurably brighter than the old oil lamps which they superseded!

The second great advance in gas lighting during this period has been the extension of high-pressure gas lighting, of which until about ten years ago only a few isolated experimental examples were in existence in London.

A number of experiments in this direction were made about the year 1900. We find that in 1901 Blackfriars Bridge was lighted on the Sugg high-pressure system, 300-c.p. lamps, supplied with gas at a pressure of 10 inches, being used. This represented a marked rise in the standard of gas street-lamps as compared with the ordinary low-pressure lamps of that time, which were rated at about 60 candles. Tests carried out in Westminster in 1902 showed that the average candle-power of the arc lamps employed was 670 c.p., the flat-flame burners and low-pressure mantles gave 61 and 58 candles respectively, and the average of the Sugg high-pressure lamps worked out to 494. In 1901 a paper was read by Mr A. W. Onslow describing the installation at Woolwich Arsenal, where a pressure as high as

54 inches was successfully used; the author predicted that the use of gas at this pressure would become general, and that lamps of 1400 c.p. would soon be considered desirable for street lighting. At the present time pressures considerably in excess of that named above are sometimes used. The lamps recently installed in the City of London and in Westminster give several thousand c.p., and are stated to have an efficiency of about 60 c.p. per cubic foot of gas.

During the last few years the number of streets brilliantly lighted by this means in London has enormously multiplied, and the progress of the method in many Continental cities has also been very rapid.

In electric lighting there have been equally striking developments. Whereas during the last twenty years of the nineteenth century no radical departure from the original glow-lamps of Swan and Edison principle had been witnessed, we have within the last decade seen the introduction of metallic-filament lamps yielding more than three times the light for the same consumption of energy. We have likewise seen the introduction of flame arc lamps, in which chemically treated carbons have trebled the efficiency of the older lamps, and enabled a light of several thousand c.p. to be obtained. The same high order of efficiency is claimed for the latest forms of mercury-vapour lamps; and there are also entirely novel methods of lighting, such as the Moore tube system, which depends on an electrical discharge through long tubes of rarefied gas and presents a remarkable departure from customary methods of illumination. More recently still we have heard of the use of the "rare" gas neon for vapour tube lighting, and even of high candle-power incandescent lamps consuming only 0·5 watt per candle!

Meantime lighting by acetylene has completely passed the experimental stage. Advances in lighting by petroleum, spirit, and paraffin have also been made (notably in the application of these methods to lighting by incandescent mantles), while other new processes, such as the petrol-air gas system (in which a mixture of petrol vapour and air of constant composition is generated and led through pipes like an ordinary gas supply), have also made their appearance and are proving their special applicability in directions not met by the older methods of lighting.

We see, therefore, that there is now available a wide choice of illuminants, and the problem of deciding their respective fields

of action is not a simple one. Whereas the consumer of fifty years ago was often restricted to a single illuminant, he has to-day many alternative systems to select from.

Naturally, this development in methods of lighting has led to a continuous rise in the standard of illumination. Owing to the lack of adequate methods of measurement in past times we have few definite records of the actual intensity of illumination employed, but we may surmise that the standard of artificial illumination, even in the last century, was far below what is considered reasonable to-day.

One can hardly doubt the immense influence of this progress in artificial lighting on social life. We have seen how, simultaneously with the development of public lighting, the security of our streets has steadily improved. Advances in illumination, as well as improved means of locomotion, have done much to facilitate social intercourse. At one time it was tacitly assumed that when darkness fell the day's work was done. Nothing remained but to retire to sleep until daylight was again available. At the present time most people rely mainly on the evening in order to meet their friends, and the hours of darkness can be used for business and recreation with almost the same facility as the daytime. In this way alone light has more than justified its reputation as a civilising agent.

To improved means of lighting must also be ascribed much of the remarkable rapidity in the march of ideas to-day. The spread of education during the last century and the remarkable development of newspapers and printed matter are largely traceable to better methods of illumination in the home, for this alone has encouraged the taste for evening reading.

Naturally, too, the introduction of better illuminants has brought with it many novel uses for light. In our theatres, concert halls, and restaurants light has long played a conspicuous part. Artificially illuminated skating-rinks, swimming-baths, and covered lawn-tennis courts are already accepted as a commonplace by the new generation. Illumination, from being a menial service, is becoming an art and a science.

The Illuminating Engineering Movement.

All these remarkable developments naturally led engineers to take a closer interest in illumination. There were a considerable number of papers on the subject read before scientific and

technical societies all over the world, and there is now an ever-increasing number of references to lighting matters in the technical press.

It was soon recognised that this branch of knowledge had become too complex to be dealt with by any existing expert, and the suggestion was made by one of the writers, in a paper before the Royal Society of Arts (London),[1] and subsequently in an article in *The Electrical Magazine* in the same year,[2] that a new specialist—"the Illuminating Engineer"—was needed.

It was pointed out that at that time it was almost impossible to find a man who had an adequate knowledge of the various illuminants and who was in a position to consider their merits impartially. It was easy to find engineers who knew a good deal about electric or gas lighting, but it was a very difficult matter to find a man who understood both; and it was still more difficult, in deciding on a system of lighting, to secure impartial and useful advice as to whether gas, electricity, acetylene, petrol-air gas or any other illuminants should be employed. Moreover, although there were men who understood about *lamps*, there were few indeed who could claim to have fully studied *illumination*. The science of making use of light, the best method of arranging lamps for different classes of work, the choice of appropriate shades and reflectors, the effect of light upon the eyes, the amount of illumination requisite for various purposes—all these were matters that had not yet been sufficiently appreciated or studied.

Naturally, time would be required to evolve such an expert. Illumination—the proper application of light in the service of mankind—is not a purely engineering matter. The new specialist should understand the effect of light upon the eyes and the hygienic aspects of illumination; he should also have studied the artistic side of the subject, so as to be able to co-operate with the architect effectively in arranging for the lighting of buildings of architectural distinction; and he should also understand the measurement of light and illumination.

Until quite recently no attempt had been made to collect this information, and to show its bearing on lighting problems. For example, if anyone wished to review the progress in illumi-

[1] "The Progress in Electric Lighting," by Leon Gaster, *Jour. of the Royal Society of Arts*, London, 9th Feb. 1906.

[2] "The Need for the Illuminating Engineer," by Leon Gaster, *Electrical Magazine*, April 1906.

nation as a whole, he had first to read through the transactions of the various bodies concerned with electric developments of all kinds, and then to do the same in the case of literature devoted to gas, acetylene, etc. As a rule the references to lighting matters were few and far between. In the same way much work had been done on the physiological effects of light and its influence on the eye, but this information was packed away in the records of ophthalmological and medical researches in various countries, and, when found, was usually in a technical form not readily applicable to illuminating engineering. The literature of photometry and the measurement of illumination was particularly scattered; almost every kind of scientific society, physical and physiological, engineering and optical, occasionally dealt with the subject from their respective points of view.

It was therefore necessary, before illumination in all its aspects could be properly studied, to provide a centre of information on the subject.

Two methods of accomplishing this end suggested themselves—the starting of a journal, and the organisation of a society in order to provide an impartial and international platform for the discussion of lighting matters. The issue of *The Illuminating Engineer* was announced in a paper before the Association of Engineers in Charge in the autumn of 1907, and the first number duly made its appearance in January 1908.

The idea of forming an Illuminating Engineering Society, originally suggested in 1906, was again brought forward on the occasion referred to above.

The actual decision to form the Illuminating Engineering Society was taken at a dinner held at the Criterion Restaurant (London) on 9th February 1909.[1] A draft constitution was drawn up by a committee appointed on that occasion, and subsequently ratified on 25th May; and on 18th November of the same year the inaugural address was delivered by its first president, Prof. Silvanus P. Thompson, D.Sc., F.R.S.[1]

Since that date four sessions of the Society have taken place very successfully. Such subjects as "Glare" (*i.e.* the dazzling effect of illuminants improperly used), "The Measurement of Light and Illumination," "The Lighting of Schools, Printing-works, Private Houses, Libraries, Streets," etc., have been dealt

[1] *Illum. Eng.*, London, vol. ii., 1909, pp. 154, 375, 807.

with at these meetings. The Society has received the co-operation of delegates from outside bodies, such as the Association of Medical Officers of Schools, the London Teachers' Association, the Association of Teachers in Technical Institutions, the Library Association, etc., all of whom took part in the discussions and rendered valuable assistance. Special joint committees, on which both the Illuminating Engineering Society and these bodies are represented, have now been formed to carry on the study of school and library lighting and collect further information on the subject, and have already issued interim reports.[1]

The Illuminating Engineering Society now includes among its members representatives of gas, electric, acetylene, oil, and petrol-air gas lighting; manufacturers of lamps, shades, and reflectors; medical men, oculists, architects and surveyors, professors, etc.; and its membership during its four years of existence has increased to close on 500. It is also international in its scope, and numbers among its corresponding members many of the greatest Continental and American authorities.

In taking the step of forming an Illuminating Engineering Society (in London), its founders were encouraged by the knowledge that a society with similar aims had been started in the United States in 1906 and had met with considerable success. Since that date the number of members of the American Society has risen to over 1500, and its transactions (to which frequent reference will be made in this work) have contained a fund of information of the greatest value. The American *Illuminating Engineer* was started almost simultaneously, and this too did much valuable pioneering work.

In other parts of Europe the study of lighting matters (which was taken up by some Continental engineers much in advance of their time) is being vigorously pursued. Many of the most recent developments in illuminants are of Continental origin, and their applications constantly form the subject of articles and papers before technical and scientific societies. The announcement was made two years ago that a German Illuminating Engineering Society has been founded under the auspices of the Technische Physikalische Reichsanstalt and at the joint request of the German Institutions of Gas and Electrical Engineers.[2]

[1] *Illum. Eng.*, London, July 1913, pp. 364–366; July 1914, pp. 359–368.

[2] *Zeitschr. f. Beleuchtungswesen*, 10th Nov. 1912.

Practical Applications of Illuminating Engineering.

A few examples will show the great opportunities for the illuminating engineer.

We have only to consider the millions of pounds spent annually upon lighting in Great Britain in order to realise the importance of even a small improvement in efficiency and economy. The lighting business ramifies in all directions. In other branches of engineering the actual practice of the art is confined to a few technical experts. But illumination, as has already been pointed out, is not a matter for the specialist alone. It interests literally everyone, whatever his or her vocation may be.

Lighting of Factories, Offices, Workshops.—Everyone is a consumer of light in his own home. But light is also indispensable to industry. Each variety of business presents a problem by itself and demands special treatment. The conditions of illumination required by a bank, a warehouse, or a foundry, for example, are entirely different. In spinning-works special lamps and fixtures must be selected to illuminate the rooms and machinery, and they must be placed in positions which throw the light just where it is needed. In printing-works the illumination of the machinery and of the compositors' frames require detailed treatment; and in dyeing, tailoring, chemical works, etc., there are again special circumstances to be borne in mind. It is this extra attention to detail that constitutes the distinction between modern illumination and the older methods. The expenditure on lighting of many large concerns is very great, and the effect of even a small saving throughout may amount to a considerable sum. But there are other matters—such as the influence of good illumination on the health of employees, and on the speed and exactitude with which work can be carried out—that are at least equally important, even though their effect is not so readily expressible in pounds, shillings, and pence.

It has already occurred to sanitary authorities to ask why, if pure air and food, good ventilation, and proper sanitary arrangements are considered essential, the necessity of good lighting should not also be insisted upon? An employer is rightly censured if he neglects the general health of his work-people. He is now expected to fence in and provide suitable guards for all dangerous machinery. But is it not equally reprehensible to permit conditions of illumination which strain the eyes,

accentuate the difficulties of work, and often pave the way for accidents?

These matters formed the subject for discussion at the important International Congress on Industrial Hygiene held in Brussels, under the patronage of the Belgian Government, in 1910.[1] Over 600 delegates of different nations, many of them representatives of their respective countries, were present, and it was resolved that methods of lighting in factories should be the subject of further study, and that in the case of dangerous machinery special care should be taken to ensure adequate illumination.

The first International Congress for the Prevention of Industrial Accidents took place at the end of May 1912 in Milan. The intimate connection that is believed to exist between conditions of lighting and the prevalence of accidents caused considerable attention to be given to illumination, special importance being again attached to the proper illumination of dangerous machinery.

In a paper read by one of the authors on this occasion[2] it was suggested that insurance companies might be willing to offer more favourable terms to companies whose lighting was up to a certain standard. It was also advocated that inspectors of factories should take note of the lighting conditions, and, if possible, supplement these notes by actual measurements of illumination, when accidents occurred.

The Home Office in Great Britain has also shown itself equally alive to the importance of the matter. Recent reports of H.M. Inspector of Factories have been most explicit in laying stress on the need for more precise recommendations.[3] The recent Departmental Committee on Accidents in Factories and Workshops[4] likewise pointed out the need for some standard of good illumination, and suggests that investigations in this direction should be undertaken. It is added: "But, even before precise data on this point are available, it is recommended that inspectors should be given statutory power to require adequate lighting in

[1] *Illum. Eng.*, London, Sept. 1910, p. 599.

[2] "The Value of Good Illumination as a Means of Preventing Industrial Accidents," L. Gaster, *Illum. Eng.*, July 1912, p. 337.

[3] Reports of H.M. Chief Inspector of Factories, see *Illum. Eng.*, London, vol. ii., 1909, p. 466; vol. iii., 1910, p. 493; vol. v., 1912, pp. 380, 418.

[4] Departmental Committee on Accidents in Factories, *Illum. Eng.*, vol. iv., 1911, p. 401.

all places where work is done, and in all places which are a source of danger by reason of insufficient lighting."

A valuable summary of existing legislation on the subject was issued in 1907 by the Conseil d'Hygiène de la Seine in Paris.[1] A noteworthy step has just been taken by the French Government in appointing a most representative committee, on which distinguished oculists, gas and electrical engineers, inspectors, and others will serve, to report on the hygienic aspects of lighting, including its relation to vision and defects of eyesight, the best methods of measuring illumination, and the possibility of framing a standard of the illumination required for different classes of work.[2]

Still more recently the Home Secretary in Great Britain promised, in response to a question by Dr Arthur Lynch in the House of Commons, to appoint a Departmental Committee on Illumination. In 1913 this committee was actually formed, and is now at work. The function of the committee is "to inquire and report as to the conditions necessary for the adequate and suitable lighting (natural and artificial) of factories and workshops, having regard to the nature of the work carried on, the protection of the eyesight of the persons employed, and the various forms of illumination." The committee are:

Dr R. T. Glazebrook, C.B., F.R.S., Director of the National Physical Laboratory (Chairman); Mr Leon Gaster, Prof. Francis Gotch, D.Sc., F.R.S., Mr J. Herbert Parsons, M.B., D.Sc., F.R.C.S., Mr W. C. D. Whetham, F.R.S., and Sir Arthur Whitelegge, K.C.B., Chief Inspector of Factories. The secretaries of the committee are: Mr D. R. Wilson, one of his Majesty's Inspectors of Factories, and Mr C. C. Paterson, M.I.M.E., A.M.I.C.E., of the National Physical Laboratory.

Concert Halls, Shops, Restaurants, Theatres, etc.—When one turns to the consideration of concert halls, shops, restaurants, etc., one appreciates the value of enterprising methods of lighting as a means of attracting the public. It cannot be too strongly insisted upon that the person who designs the lighting in such cases should first make himself *au fait* with the nature of the business to be carried on, and design the illumination accordingly. In restaurants the scheme of lighting to be adopted is absolutely dependent on the class of customers catered for. In the same way the objects aimed at in the shop window (which vary much according to the nature of the shop and the locality)

[1] *Illum. Eng.*, London, vol. ii., 1909, pp. 229, 319.
[2] *Ibid.*, vol. iv., 1911, p. 455.

must be carefully borne in mind. In the higher branches of shop lighting there is an undoubted demand for the man who understands how to combine the arts of window lighting and window dressing.

Lighting of Schools, Colleges, etc.—A most important opening for the efforts of the illuminating engineer is afforded in the natural and artificial lighting of schools and colleges. In the London County Council schools alone there are stated to be over 1,000,000 children, each of whom may suffer if work is carried on with imperfect conditions of lighting. The prevalence of defective eyesight among children, an affection which appears to become steadily worse during school life, has lately given much concern to medical authorities, and it is pointed out that this may, in a large measure, be the consequence of defective illumination.[1] Naturally, insufficient or ill-directed light increases the tax on the eyes, and, as Dr Kerr, the Medical Education Officer to the London County Council, has shown, the effect on the general health and physical development of the child of a strain of this kind may also be serious. The question of lighting is now engaging the attention of school authorities all over the world. The problems demand the combined skill of the medical officer, the architect, and the lighting engineer. In Germany and in the United States it has been advocated that, before a new school is built, the plans should be examined by a committee composed of these experts. In some cases this plan has already been put in operation, with beneficial results.

Street Lighting.—During the last five years the progress in street lighting has been remarkable.

Yet constant improvements are still being made, and it is significant that both the City of London and Boston (U.S.A.)[2] have recently sent deputations to the Continent to report upon the methods employed. A noticeable point at the present time is the increased interest taken in the distribution and *use* of the light from street illumination as apart from the lamps themselves.

The requirements of street illumination have entirely changed. At one time, as we have seen, illumination was intended mainly to promote security, to enable men to walk the streets in safety.

[1] See an article summarising evidence on this subject from the schools in Great Britain, the Continent, and the United States, *Illum. Eng.*, London, vol. i., 1908, p. 58.

[2] *Illum. Eng.*, London, vol. i., 1908, p. 617 ; vol. ii., 1909, pp. 526, 623, 677.

But the ever-growing stream of traffic, the introduction of motor vehicles, and the speeding up of locomotion generally make much more severe calls on the present methods of lighting. We now seem to be on the eve of a more scientific conception of the aims and objects of street lighting. There is a desire on the part of representatives of gas and electric lighting to have some common understanding as to what these aims and objects should be, and how the qualities of different systems of lighting should be tested. In response to this feeling a joint committee—composed of members of the Illuminating Engineering Society, the Institutions of Gas and Electrical Engineers, and the Association of County and Municipal Engineers—is now deliberating on this question, and is considering the possibility of framing a joint specification which would be acceptable alike for gas and electrically lighted streets.[1]

Public Buildings, Picture Galleries, Museums, Churches, etc.—The consideration of the lighting of public buildings, churches, museums, etc., opens out a new aspect of illuminating engineering. In many of these cases the cost of the illumination should be (within limits) of relatively small consequence. The chief requirement is to secure conditions which are worthy of the dignity of the building and suitable for the purpose to which it is devoted.

It need hardly be pointed out how dependent is the artistic appearance of an interior on the method of illumination. Moreover, a room containing pictures or miscellaneous objects of interest must be illuminated before they can be seen. The appeal is made through the eye. Good methods of directing the light on the exhibits do much to display their value; bad methods make their study an exasperating labour.

Design of Fixtures, Globes, Shades, and Reflectors.—The popular imagination has been so captivated by the succession of inventions in illuminants that the recent progress in accessory apparatus—such as fixtures, globes, and reflectors, etc.—has been somewhat overlooked.

Yet from a scientific standpoint these advances have been equally important. The most powerful lamp in existence is of little value if the light is not wisely used, and we have need for scientifically designed globes and reflectors, which tone down

[1] A draft specification prepared by the committee was presented in a paper before the Illuminating Engineering Society (London) by Mr A. P. Trotter in 1913 (*Illum. Eng.*, May 1913).

excessive brilliancy when needful and direct the light where it is required for specific purposes.

Equally important is the design of fixtures, which present an excellent field for the combined efforts of the decorative craftsman and the lighting engineer. All these accessories must be considered from two distinct aspects. We must secure their practical utility for the distribution of light and also preserve their decorative appearance. It is in the combination of these two qualities that the hand of the skilled designer is shown.

The Measurement and Calculation of Light and Illumination.—The measurement of light and illumination might almost be said to form the basis of scientific illuminating engineering. Before illumination can be effectually studied one must have methods of measurement, so that we may keep a record of existing conditions, ascertain positively when any change has taken place, and be able to support one's opinion by an appeal to actual facts and figures.

At one time photometry was regarded merely as an interesting and difficult subject for philosophic study. It is only recently that its commercial value has been appreciated, but we already stand in a very different position from a few years ago. Much of the old confusion, due to the fact that a number of different standards of light were in use, has now been swept away, and our method of measuring the candle-power of lamps in the laboratory has been greatly improved. Perhaps the greatest step, however, has been the introduction of simple and reliable instruments for measuring illumination.

The great value of these measurements to those interested in the study of street, school, and factory lighting, etc., will be understood. They are, however, equally serviceable to the expert lighting engineer in enabling him to check the results of his calculations. He can now work out beforehand exactly how the illumination should be distributed, and subsequently ascertain by measurements whether his calculations are correct.

It need scarcely be added that this advance in the precision of measurement has been accompanied by a corresponding demand for revision of the terms, symbols, and nomenclature used in illuminating engineering, and quite a number of national and international committees have been at work on this subject. A movement was recently set on foot to consolidate these independent efforts by the appointment of a single International Commission on Illumination, representing the various illumin-

ants and thoroughly international in its scope, to deal authoritatively with these matters. At the International Electrical Congress held in Turin in September 1911 the following resolution was passed unanimously:

"That this Congress deems it desirable that an International Commission should be nominated in order to study all systems of lighting and technical problems connected therewith; and, having been informed that the Illuminating Engineering Society of London has the intention of forming such a Commission, and of putting itself in touch with the other existing national and international photometric committees, approves their taking the initiative in this respect." [1]

Subsequently, at a meeting of the International Photometric Commission, held in Berlin in August 1913, the International Commission on Illumination was duly formed, the first president being Prof. Th. Vautier and the hon. secretary Mr C. C. Paterson, of the National Physical Laboratory, England.[2]

Besides dealing with purely photometric matters, nomenclature, etc., the commission will have power to occupy itself with matters of general industrial importance in connection with illumination, such as the hygienic effects of various systems, the establishment of certain standards of illumination for specific purposes, etc.

National committees are also being formed in the various countries to study the subject.

Conclusion.

In this chapter we have traced the development of methods of producing light from their first beginnings.

We have seen that the last decade has been marked by exceptionally rapid progress in the manufacture of light. What will the next ten years bring forth? Possibly we shall see advances in the invention of illuminants which put into the shade those which seem to us so remarkable to-day. But two things, it may confidently be predicted, we *shall* see—a great advance in the knowledge how to make the best use of the light we have been at such pains to obtain, and the steady development of methods of scientific illumination.

[1] *Illum. Eng.*, vol. iv., 1911, p. 617. [2] *Ibid.*, vol. vi., 1913, p. 491.

CHAPTER II.

GAS LIGHTING.

Early Types of Burners—The Welsbach Mantles—Cotton, Ramie, and Artificial Silk Mantles, etc.—Useful life, Durability, etc.—Inverted Burners and their Advantages—Thermostatic Control—Horizontal and Inclined Burners—Self-contained High-efficiency Lamps (Scott-Snell, Lucas, etc.)—Low-pressure High-efficiency Lamps—High-pressure Gas Lighting—Keith, Grätzin, and other Lamps—High-pressure Lighting in the Streets of London, "Parade Lighting," etc.—High-pressure Gas and High-pressure Air—Central Suspension, Raising, and owering Gear—Distance Extinguishing and Ignition (Electric, Pneumatic, Pressure-wave, etc.)—Self-lighting Devices and Pyrophoric Alloys—Cost of Gas Lighting—Maintenance, its Benefit to the Consumer—Future Possibilities.

In Chapter I. something was said on the history of gas lighting. In the present chapter it is proposed to deal mainly with gas illuminants, especially the progress of the last few years, and to show how these great improvements in luminous efficiency have been secured.

The subject is a very wide one. The problems connected with the manufacture and distribution of gas must be left to the able text-books that treat on these subjects; nor can we enlarge very fully on the scientific phenomena underlying the nature of flames and combustion—a fascinating field of investigation which has received much study from eminent chemists. It is also proposed to discuss lanterns and shades and methods of *directing* light more fully in a later chapter. Our present concern is mainly with the actual lamps by which the light is *produced*.

Early Types of Burners.

The earliest methods of obtaining light from town gas consisted in merely burning a jet issuing from a convenient aperture. The original burners seem to have simply utilised holes through which the gas was allowed to escape and ignited. Soon it was found desirable to make the tips of the burners of some material which was not readily destroyed by heat, steatite being used in

the great majority of burners of this kind in use to-day. The question of the best form and size of the aperture was also, naturally, a matter for concern, the so-called "batswing," "union jet," and other types utilising slits or several holes in the steatite cap. Some typical shapes of this kind are shown in fig. 7.

The original burners were naturally very inefficient, judging by present standards.

A considerable proportion of gas was allowed to escape unburned, or at least incompletely burned, into the atmosphere, so that the maximum possible brightness of the flame was not attained. In addition, the flames were inclined to smoke owing to incomplete combustion, and the unused gases escaped and polluted the atmosphere. With a more complete knowledge of the nature of combustion these early defects were largely remedied. Burners were designed to secure a maximum flame temperature, and the theory of the luminosity of flames has been exhaustively studied.[1] Very soon, however, a limit was reached in the possible efficiency; it was found difficult to secure more than 2 to 3 c.p. per cubic foot of gas of ordinary quality. It must be remembered, however, that the quality of the illuminating power of gas may vary in different localities. For example, the Act of 1860 prescribed that town gas, burned under specified conditions with a certain type of burner, should give 15 c.p., but the local cannel coal in Scotland gave as much as 20.

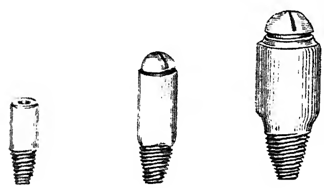


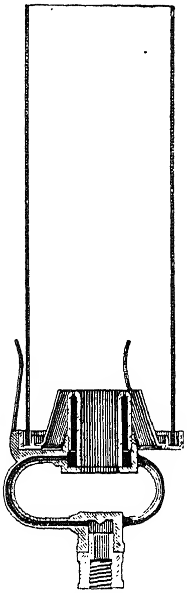
FIG. 7.—Various forms of flat-flame burners

Ordinary flat-flame burners required about $\frac{7}{10}$ths of an inch of water pressure. When this value was greatly exceeded they tended to roar and smoke; consequently, it became usual to include in the burner a governing device, such as a small cone, which rose and checked the admission of gas should the pressure rise above the desirable point. With the introduction of incandescent mantles it was found necessary to raise the general standard of pressure somewhat, and this also led to the introduction of "economisers," small caps which were fitted on to existing

[1] See, for example, an exhaustive paper by W. H. Fulweiler, "The Theory of Flame and Incandescent Mantle Luminosity," *Trans. Amer. Illum. Eng. Soc.*, Feb. 1909.

flat-flame burners and adapted them to the changed conditions, enabling better conditions of combustion to be secured with a more luminous flame.

With the introduction of electricity, gas began to feel the need of lamps of higher candle-power and greater efficiency. The intensity of lamps could of course be increased to a certain extent by using burners consuming more gas, or by introducing into a single lantern a larger number of burners. But what was really required was some means of securing more light



(a) Sugg's Argand burner, No. 1.

(b) Argand burner, equipped with "Christiania" opal shade.

FIG. 8.—Argand burner.

for a given consumption of gas. The ordinary flat-flame type seemed to be capable of little substantial improvement in this respect. The Argand round burner yielded a slightly higher efficiency, but the long flame was unsteady and readily affected by draughts. One possibility, increasing the illuminating power of the gas burned by enrichment, was not commercially feasible. A very similar method, however, was employed in the "albo-carbon" burner, in which the gas was caused to circulate over naphthalene, a by-product from gas manufacture. This eventually volatilised the naphthalene and enriched the flame, giving as much as 5 to 6 c.p. per cubic foot per hour. A projecting flange

of metal placed over the flame served to collect the heat and shorten the time necessary for the naphthalene to volatilise, which, however, was still considerable.

A more successful attempt to increase the efficiency of gas lamps was exemplified in the regenerative lamps of Siemens, Wenham, Sugg, and others. In these "suns" the gas to be consumed was caused to pass along tubes which were heated by the flame, and this preheating led to a considerably increased flame temperature and efficiency. As much as 50 to 200 c.p. could be obtained by this means, and the light was also favourably distributed, being mainly directed downwards. The efficiency was stated to be about 8 to 9 c.p. per cubic foot per hour. The first cost was relatively heavy, however, and the intense heat caused the burners to wear out somewhat rapidly.

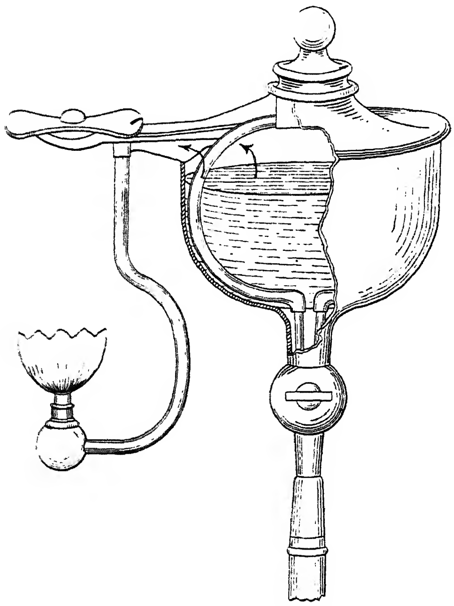


FIG. 9.—Albo-carbon burner.

Nevertheless, these defects might probably have been largely mitigated, and the lamps would have had a more important application but for the arrival of the more efficient incandescent mantle.

THE COMING OF THE INCANDESCENT MANTLE.

The coming of the incandescent mantle entirely changed the aspect of gas lighting. Hitherto the important factor had been the illuminating value of the gas, and existing legislation had been framed with the intention of maintaining this quality. But the incandescent mantle depended on an entirely different principle, namely, the use of the gas as a *heating* agent to bring a web of suitable material to incandescence.

This principle itself was not new. The invention of the

limelight in 1826 by Thomas Drummond is generally regarded as one of its first applications. Tessie du Motay,[1] in 1867, attempted to replace the lime by zirconia, and so secure a higher efficiency; and Alexander Cruickshanks, following Davy, devised mantles composed of platinum wire covered in with lime and heated by non-visible luminous gases as early as 1839. The other essential element, the burner, dates from Professor Bunsen's invention in 1852.

Welsbach's great discovery was announced about 1883. His first mantles consisted of a cotton woven cylinder soaked in solutions of the rare earths, lanthanum being one of the first employed. The vivid incandescence of lime in the intense heat of the oxyhydrogen flame was familiar to people, but it was a revelation to discover that there were substances which would incandesce so persistently and brilliantly in the comparatively low temperature of the bunsen flame. It appears that these early mantles, while yielding a bright light, disappointed Welsbach by crumbling to powder in the course of a few days.[2]

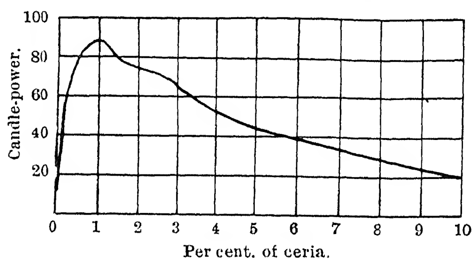


FIG. 10.—Relation between candle-power and percentage of ceria in the incandescent mantle.

But presently Welsbach made a further remarkable discovery, namely, that by adding a minute proportion of ceria to the thoria in the mantle the intensity and duration of the luminous efficiency could be substantially increased.

The curve in fig. 10, as given by Whitaker and other authorities, illustrates the well-known connection between the luminous efficiency of the mantle and the percentage of cerium. There is a certain value, about 0·9 per cent., which appears to give the best possible result, and any increase or diminution is prejudicial. This percentage is said to be adhered to without much variation even in the mantles of to-day. There have, however, been modifications made in the introductions of other small ingredients, chiefly with a view to improving the colour of the light.

[1] Drysdale, "A Brief History of Artificial Lighting," *Illum. Eng.*, London, vol. i., 1908, p. 198.

[2] Barrows, "The Work of Auer von Welsbach," *Trans. Illum. Eng. Soc. U.S.A.*, vol. iv., Oct. 1909, p. 569.

Nichols[1] has shown how the peculiar greenish quality of light due to "selective radiation" has become much less evident in modern mantles, and the effect of varying the percentage of cerium and thorium on the colour of the light emitted has also been dealt with by Simonini.[2]

It would be out of place to enter deeply into the many theories that have been put forward to account for the high luminous efficiency of the mantle and the singular effect of such a minute percentage of ceria. Those interested in this question may also consult the lectures of Prof. Vivian Lewes before the Royal Society of Arts (London)[3] and Prof. Rubens before the British Association. A useful summary of published researches by Féry, Killing, Bunte, and others on this point has also been recently given by Lévy.[4]

The discovery of Welsbach brought the chemistry of the incandescent mantle to a successful and practicable stage, but there remained much patient work in the details of manufacture before it proved a permanent commercial success. The discovery was made in 1890, but it was not until ten years later that incandescent gas lighting could be said to have firmly and permanently established itself in Great Britain.

There are quite a number of steps in the processes of manufacture, each of which has its influence on the subsequent performances of mantles. In the ordinary course a web of suitable material must first be formed, and this web is immersed in and impregnated by a suitable solution of the incandescing material. Subsequently the web is dried and burned away, leaving only the skeleton, consisting of the active material, which should hold together in a fairly durable condition. Formerly mantles were afterwards invariably steeped in collodion so as to strengthen them for transport purposes, and this coating of collodion had to be burned off by the consumer before the mantle was put into use, although more recently it has been found possible to dispense with this process.

All these operations have been the subject of a large number of patents, and the literature on the subject is very

[1] *Trans. Illum. Eng. Soc. U.S.A.*, May 1908, p. 327.

[2] "Notes on Chemical Luminescence of Rare Earths," *Trans. Illum. Eng. Soc. U.S.A.*, vol. iv., Oct. 1909.

[3] "The Incandescent Mantle and its Uses," Cantor Lectures. Delivered May 7, 14, 21, 1900.

[4] *L'Éclairage à l'Incandescence par le Gaz*, pp. 35–48.

extensive.[1] The methods of weaving the mantle web, and in particular the strengthening of the mantle at the neck (in the case of the upright type), have been the subject of much study. Formerly it was considered necessary for the process of burning off, which required very delicate manipulation, to be carried out by hand, but more recently burning-off machines have been successfully applied to the process on a large scale.[2] Yet another factor which affects the final result is the nature of material used in the web; originally cotton was exclusively employed, afterwards Indian hemp, Chinese grass, or ramie fibre, and still more recently artificial silk.

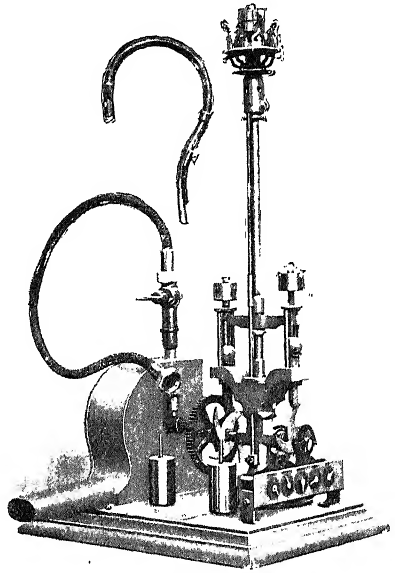


FIG. 11.—Moon-Woodall shocking machine for testing incandescent mantles.

A poor mantle may fail in practice in quite a number of ways. It may rapidly split and tear through vibration or the constant impact of the flame in lighting up and extinguishing, simply as a result of mechanical weakness. On the other hand, a mantle may be durable in this respect, but yet its light may deteriorate because the chemical material loses its luminous activity or peels away or disintegrates. Also, its light may diminish because the mantle in course of time alters in shape, so that the active material is gradually withdrawn from the hot region of the flame. All these possibilities have to be guarded against, and in the latest forms of mantles have been largely overcome. Methods of testing mechanical strength and durability have been devised; for example, the "shocking machines," which administer a regular

[1] Böhm, "Notes of Incandescent Gas Lighting," *Illum. Eng.*, vol. ii., 1909, pp. 227, 326, 395, 628; *Die Fabrikation der Glühkörper fur Gasglühlicht* (1910).

[2] Böhm, "Recent Advances in the Manufacture of Incandescent Mantles," *Illum. Eng*, London, Aug. 1911, p. 461.

vibration to mantles, the intention being to compare the durability of different types by the number of shocks each can withstand before breaking.[1] A variety of testing apparatus which has been largely used in this country is the Moon-Woodall machine,[2] shown in fig. 11. Krüss[3] has also devised an optical device for observing and recording the change in shape of a mantle during life. J. H. Coste and W. E. F. Powney[4] have recently advocated the adoption of a standard specification for mantles, in which measurements on the lines suggested play a prominent part.

Some of the recent improvements in mantles have been exhaustively discussed by Böhm, Drehschmidt, Müller, and others.

Many improvements have been made in the actual methods of knitting the yarn. Even more important have been the developments in the material selected for the fabric. Natural cellulose, in the form of knitted cotton, was at first exclusively employed. This material, as originally prepared, presented several defects. It was difficult to find a variety of cotton in which sufficiently long threads occurred; as a rule the individual threads seen under the microscope proved to consist of a woolly bundle of small ones twisted together, and naturally they became disintegrated somewhat rapidly in the process of burning.

A distinct improvement was made by the introduction of ramie fibre, or, as it is variously called, "Indian hemp," or "Chinese grass." The individual threads making up the fabric were in this case more continuous; its durability was greater; and it was found that more uniform fibres could be drawn out on the machine.

Yet another step in the application of natural cellulose for mantle construction was the treating of the material by a special process, known as "mercerising," by which it was rendered much more durable and silky in texture. Cellulose of this character is extensively employed in the Plaisetty mantles.

It has also been long recognised that the coating of mantles with collodion, so as to strengthen them for transport, was open to certain objections, and that the subsequent burning off of this coating by the consumer necessarily impaired to some extent the strength and efficiency of the mantle.

1 "Drehschmidt Shocking Machine," *Jour. of Gas Lighting*, 25th Dec. 1907.
2 "Moon-Woodall Shocking Machine," *Jour. of Gas Lighting*, 22nd Oct. 1907.
3 *Jour. f. Gasbeleuchtung*, 2nd Nov. 1907.
4 *Jour. of Gas Lighting*, 10th Jan. 1911.

Attempts have therefore been made to prepare "non-collodionised" mantles, which are not subjected to this process of being dipped in collodion, but are nevertheless made in a form sufficiently strong to withstand transport. A notable step in this direction has been the preparation of soft mantles. These consist merely of the impregnated fabric, which has not been subjected to the burning-off process and which is therefore quite soft, strong, and pliable. Such mantles undergo burning off when they are first placed on the burner and ignited by the consumer, the mantle automatically adapting itself to the shape of the burner flame, and the nitrates of zirconium and thorium being reduced to oxides meanwhile. At one time these non-incinerated mantles were very unreliable in quality after quite a short period of storage, unless they were kept in special moisture-proof sealed cases. These and other difficulties are stated to have been now substantially overcome in the best modern makes.

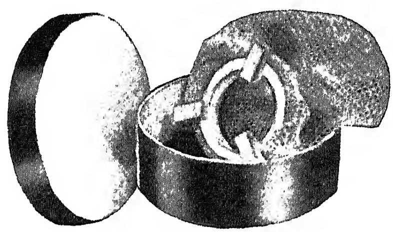


FIG. 12.—Showing "Monarch" soft mantle and box for transport.

To sum up, the advantages claimed for the soft type of mantle are:—

(1) It can be handled with impunity before incineration and can be packed in an exceptionally small space for storage.

(2) The incinerated fabric is not subjected to collodion, with the resulting detrimental effects.

(3) The pliable nature of the mantle after incineration readily adapts itself to the shape of the flame for which it is intended.

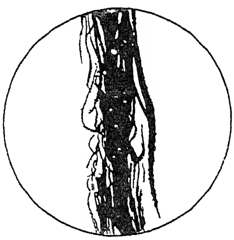
(4) The mantle can be stored and kept previous to incineration without the danger of deterioration due to moisture, etc. The mantle, it is said, can even be dipped into water without ill effects.

There remains to be mentioned an interesting development in the preparation of the web used in mantles, namely, the manufacture of artificial silk. We see here a striking resemblance to the course of events in the manufacture of filaments for electric glow-lamps. Originally bamboo fibres were employed for this purpose, but their lack of uniformity was a great drawback. Subsequently the carbon filament was prepared from artificial

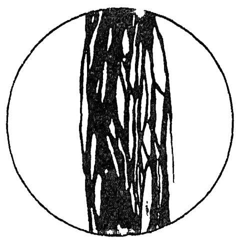
material obtained by squirting a solution of cellulose, and much more homogeneous filaments were then secured.

In the same way artificial silk was prepared synthetically by several investigators, including Plaisetty and Knöfler, just at the beginning of this century, for use with incandescent mantles, and the same principle is employed in Terrel's patents about this date. Zdanowich[1] states that there are now in use three varieties, produced by the Chardonnet, Copper-ammonia, and Viscose processes.

An interesting characteristic of these artificial silk mantles is that even after being used for some time they can be lifted off the support and folded over the finger without breaking up. A much more uniform and durable skeleton of active material



Ramie.



Artificial silk.

FIG. 13.—Showing appearance of ramie and artificial silk after burning 1000 hours.

can also be obtained. Nass[2] and Müller[3] have recently given some interesting particulars on the subject, laying stress on the long threads secured. These constitute an improvement on the short choppy web which natural cellulose appears to yield.

Fig. 13 is based on two microphotographs given by Nass, which illustrate the greater uniformity of the artificial silk mantle as compared with ramie, after 1000 hours' burning. The silk mantle fibres are still quite uniform, but the ramie is jagged and torn. The same authority adds that on a high-pressure street burner artificial silk mantles were found to last for seven weeks, while ramie web of the same character would only stand for six days. Whitaker,[4] in a recent paper before the American Illuminating Engineering Society, states that the deterioration in light during

[1] *Jour. of Gas Lighting*, 19th Sept. 1911.

[2] *Jour. f. Gasbeleuchtung*, 23rd Sept. 1911.

[3] *Jour. f. Gasbeleuchtung*, 6th May 1911; *Zeitschr. f. Beleuchtungswesen*, 30th April 1911.

[4] *Trans. Amer. Illum. Eng. Soc.*, May 1910.

1000 hours was found by him to be 35 to 40 per cent. in the case of cotton and 15 to 25 per cent. in the case of ramie. With an artificial silk mantle, however, there was, under favourable circumstances, no perceptible diminution in light after 2000 hours, and only 5 to 10 per cent. after 4000 hours. In considering these results one must, no doubt, bear in mind the distinction to be drawn between results obtained in practice and in the laboratory; but there seems no doubt but that exceptional improvements have been obtained during the last few years.

Those interested in this subject are referred to an article by Böhm,[1] who, in summarising recent progress in this field, gives a special account of the latest Cerofirm process of treating artificial silk mantles.

A form of mantle which has received some notice—the so-called "Hella Bushlight"[2]—constitutes a reversion to the methods employed by Edison and others in very early patents of utilising rods of active material instead of impregnating threads. It is claimed that these bundles of rods possess great durability, but until such mantles have found their way into general practice one must postpone judgment on this point.

One other recent attempt to improve the durability of mantles—the "Robinlyte" process—should be mentioned. This mantle consists of a series of flexible crimped threads which, it is claimed, can be poked or folded without injury. It is also stated that the mantle is proof against the defects of splitting and cracking, and that the bundle of threads is advantageous because an exceptionally large area of active surface is presented to the flame, to which the mantle readily adapts itself.

A word or two may also be said on the subject of high-pressure mantles. The conditions in this case are somewhat different from those prevailing on a low-pressure supply. The mantle is exposed to a continuously higher temperature and a greater flame velocity, so that exceptional mechanical strength is entailed. Double mantles (one inside the other) are frequently employed in order to obtain greater durability.

It may perhaps be expected that some curves should be given illustrating the fall in candle-power of incandescent mantles during life. The results available, however, prove on examination to be so conflicting that little useful information could be

[1] *Illum. Eng.*, London, vol. ii., 1909, pp. 227, 326, 395, 628; see also *Jour. of Gas Lighting*, 25th Dec 1906.

[2] *Illum. Eng.*, vol. i., 1908, p. 827; *Jour. of Gas Lighting*, 4th Aug. 1908.

given in this way. We may, however, refer to the experiences of Lauriol,[1] Bond,[2] and others.

The truth appears to be that mantles differ vastly in quality, and the care devoted to the burner is an important factor.

There can, however, be no doubt that the best mantles give much better results than those in use a few years ago, and Mr F. W. Goodenough, in his recent paper before the Illuminating Engineering Society (London), expressed the view, as a result of long practical experience, that a good modern mantle should not diminish appreciably in candle-power during 500 hours, and by not more than 10 per cent. in 1000 hours.

The Incandescent Burner.

It must, however, be recognised that there are a number of different factors affecting the efficiency of an average gas light besides the mantle, namely, the pressure and nature of the gas burned and the burner employed. Practical conditions are often widely different from those secured in the laboratory, and it is probable that the life of a mantle in practice is more frequently terminated by breakage than deterioration in candle-power. Even a slight vibration, if persistent, must have an effect on a mantle, although it is true that the newer varieties (particularly those of the inverted type, to which reference will be made shortly) will withstand rough usage to a much greater degree than the earlier ones. The effect of such vibrations can be readily tested by means of the Moon-Woodall testing machine, alluded to above. The fact that inverted incandescent mantles are widely used for train lighting is evidence of the recent improvement in durability.

But the design of burner and the variety of chimney used have also an important bearing on the light given by a mantle. It need hardly be said that the former must be kept free of dust, and it is also necessary to secure the most perfect regulation of gas and air supplied, corresponding with the quality and pressure of the supply. Modern gas burners are provided with devices which permit of this regulation being easily made.

In the bunsen burner the essential object is to secure as hot a flame as possible for a minimum consumption of gas. The efficiency yielded by the mantle depends very greatly on the temperature of the flame, and hence on the possibility of securing

[1] *Illum. Eng.*, London, Dec. 1910, p. 733. [2] *Ibid.*, Jan. 1911, p. 51.

as perfect combustion as possible. In the case of the ordinary burner of this type air is admitted and mixed with the gas previous to its being ignited, and the relative proportions of gas and air are usually adjustable by opening and closing the air inlets. Now, it appears that perfect combustion of ordinary town gas demands a proportion of about $5\frac{1}{2}$ of air to 1 of gas. By suitably designing the burner we can make a mixture of about 3 of air to 1 of gas (with normal low pressures), but any attempt to produce a poorer mixture than this is apt to cause the flame to light back. In order to counteract this tendency,

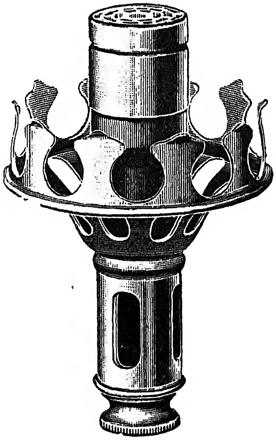


FIG. 14.—Bray upright incandescent burner, No. 2.

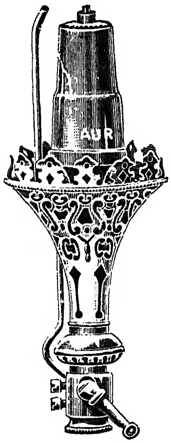


FIG. 15.—Welsbach-Kern upright incandescent burner.

wire gauze is frequently introduced into the mixing tube of the burner.

The design of the burner has proceeded with the object of bringing the gas and air into as intimate contact as possible. For example, in the Welsbach-Kern burner a tapering cone was introduced above the air inlets so that the air and gas might get thoroughly mixed before ignition, and a peculiar twisted head is added so as to produce a swirling motion of the gas, with the same intention. Again, in the Bansept burner a series of conical chambers, each opening by a small aperture into the one above, were employed. The design of this mixing-chamber forms one of the most important points in the design of modern burners.

The early incandescent burner required a pressure of $1\frac{1}{2}$ to 2 inches head of water to work successfully, but it is claimed that the best modern burners, with gas and air regulation, can be

adjusted to work on practically any pressure found in the ordinary district mains. Fluctuations in pressure may have a prejudicial effect in upsetting the conditions of combustion, causing the flame to waver and smoke, and it has been suggested that in the case of large premises a governor should be inserted at the meter.

Inverted Burners and Mantles.

A new chapter in gas lighting was opened with the arrival of the inverted mantle. Although we are now accustomed to its convenience, there was a time when even some of the greatest authorities seemed to doubt whether the initial difficulties connected with this variety of burner could be satisfactorily overcome. It was only in 1904, at the Earl's Court Exhibition of Gas Appliances, that the general public in this country realised that the inverted burner had come to stay. The process of turning the ordinary bunsen burner upside down, and the peculiar conditions under which the gas had to burn in these circumstances, led to a number of difficulties which were at first very imperfectly understood, but have since been overcome. The early burners were apt to smoke, to produce a hissing noise, and to "strike back" unaccountably, and their regulation was troublesome to the average consumer. A paper by V. A. Rettich in America in 1906[1] called attention to a number of these difficulties and attracted considerable attention at the time, and a discussion between Prof. Drehschmidt and Dr H. Krüss about that time revealed a disposition to doubt whether any substantial gain in efficiency was secured. Indeed, in 1905, at the annual meeting of the Verein von Gas und Wasserfachmännern, Prof. Drehschmidt confessed that nearly all the inverted burners available were apt to smoke!

These difficulties are now happily overcome. The advantages secured by the inverted burner are now recognised to be considerable, and some of the most important of them may be summarised as follows:—

(1) *Improved Distribution of Light.*—The shape of the upright burner is in most cases obviously far from ideal for light distribution. The burner necessarily obstructs a great deal of light and is apt to throw a dark shadow below the lamp. Apart from this, the long mantle leads to most of the light being

[1] *Illum. Eng.*, New York, vol. i., 1906, p. 95.

cast out horizontally, whereas, as a rule, one desires the majority of the light to be directed downwards. The vertical mantle is thus unsatisfactory in two ways—it obstructs the light, and it does not distribute it in a desirable manner. The difference between the two mantles in this respect is illustrated in fig. 16, in which typical polar curves of upright and inverted mantles are shown. (This method of representing distribution of light will be explained in Chapter VII. Briefly, it consists in drawing lines radiating from the source at different angles, in each case making the length of the line proportional to the candle-power

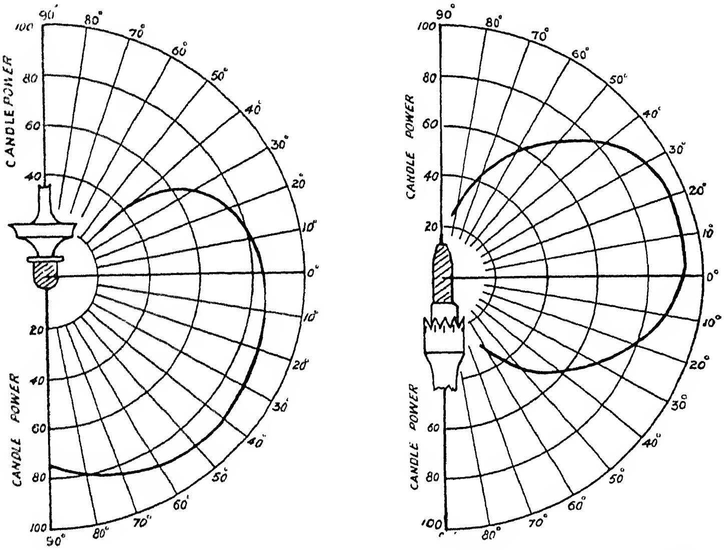


FIG. 16.—Showing distribution of light from typical upright and inverted burners giving approximately the same total candle-power.

in that direction. Thus, in the case of the upright mantle, the longest line is the horizontal one, this being, as we have seen, the direction of maximum light. The ends of such lines form a closed curve called the "polar curve of distribution of light.")

This curve may be looked upon as typical of the inverted burner, but one can vary the distribution of light considerably by altering the shape of the mantle. Some of the early small units had mantles which were almost flat, and they therefore threw practically all their light downwards. But the consequent deep shadow above the mantle was considered undesirable and a condition of things intermediate between this and the upright mantle is now preferred for general purposes.

(2) *A greater Variety Range of Candle-power can be secured.*—Whereas with the upright burner it was not easy to secure a lamp yielding less than about 50 to 60 c.p. and consuming 3 to 3½ cubic feet of gas, small units, giving only 25 c.p. (or even less) and having a proportionally smaller consumption, can now be obtained. In addition, by grouping high-power mantles together in a lantern, very powerful lights, rated up to 4500 c.p., can be obtained. By arranging for only one or several of the mantles to be lighted up, these units can be further subdivided.

(3) *Higher Luminous Efficiency.*—The fact that much less light is obstructed by the burner in the case of the inverted lamp naturally leads to an improvement in efficiency. But apart from this, it appears that the luminous efficiency is increased for physical causes. It has been found by some that the "preheating" of the gas before it is actually burned, which is very readily accomplished with the inverted burner, means that a hotter flame, and therefore better incandescence, is secured. Also that the use of a smaller more concentrated flame, such as these smaller mantles demand, has a similar beneficial effect.

It is also suggested that the flame can be more scientifically applied to the mantle so as to illuminate all parts of it to the same brilliancy; in the case of the longer upright mantle, on the other hand, one could often observe that some parts, especially the upper end of the mantle, did not attain the same temperature as the base and were not nearly so bright. Yet another interesting explanation of the improved efficiency was given by Mr Carpenter at a meeting of the Illuminating Engineering Society in 1910. He pointed out that whereas in the upright mantle the hot gases are continuously ascending and moving away from the mantle upon which they are intended to impinge, in the inverted burner they probably begin by descending, come to a stop, and then the direction of flow is reversed; as a result they act upon the mantle in a comparatively still atmosphere and their heat is much more effectually communicated to the incandescent material.

(4) *Improved Durability and Strength of Mantles.*—Perhaps one of the greatest gains in connection with inverted mantles is the improved durability. This arises partly from the nature of the mantle itself—which is shorter, more compact, and therefore less inclined to split—and partly from the nature of the support. The method of supporting the long upright mantle on a crutch was unsatisfactory in the hands of unexperienced people, and

it was a common experience for such mantles to give way at the neck. The inverted mantle, on the other hand, being supported by its entire rim, is less liable to breakage, and, should the fabric tear at one part, the whole mantle will remain supported and will not fall to pieces as an upright mantle might do. This last point is of considerable consequence for railway-carriage lighting, where a failure in a mantle should not mean the total cessation of light.

(5) *Convenience and Artistic Appearance.*—Finally, the mere fact of the light being mainly distributed in a downward direction, and the gas entering at the top, constitute an added convenience from the standpoint of fixture design; under these conditions many artistic methods of treating the lighting of interiors, which would have been difficult to attain with the upright mantle, become possible.

A few words more may be said on the design of inverted burners. In order to secure these advantages, and to avoid the defects of incomplete combustion, hissing, flashing back, etc., much care has been necessary. Some interesting papers have been read dealing with this design more exhaustively than we can do here, and the new models of gas lamps which appear each year show steady progress in detail.[1] One might also mention a recent summary of the problem by Professor Whitaker.[2]

Professor Drehschmidt was among the first to insist upon the necessity of avoiding contamination of the gas and air supply by the products of combustion, and to point out that the defects in the burners of that time arose partly through the fact that these products were forced through the mantle.[3] The access of gas and air is now carefully shielded, and metal wings or deflectors are also frequently employed to conduct away the heat and prevent discoloration of fittings.

In some burners the application of the waste heat from the burner to raise the temperature of the entering gas and air mixture is also beneficial as a means of cooling the parts of the burner over which the mixture passes. Another feature which

[1] See, for instance, "The Evolution of the Inverted Gas Light," by Professor Ahrens, *Jour. of Gas Lighting*, 21st May 1907 (abstract).

[2] Lecture at the Johns Hopkins University, Baltimore, U.S.A., 1910.

[3] "Inverted Gas Lamps," *Jour. f. Gasbeleuchtung*, 16th Sept. 1905. "The Present Condition of Incandescent Lighting," paper read at the Annual Meeting of the Verein von Gas und Wasserfachmännern 1906.

is embodied in good modern inverted burners is the provision of special hoods or deflecting wings to secure that the air supply

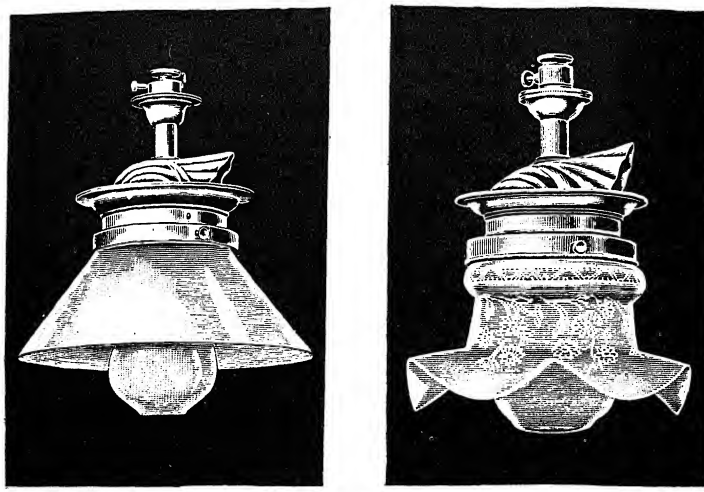


FIG. 17.—Types of Bland inverted burners.

is not contaminated by the products of combustion (note, for example, the devices shown in figs. 17 and 18). In the Bland

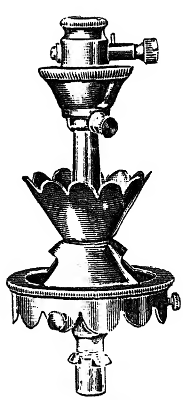


FIG. 18.—Bray "Bijou" inverted burner.
(Consumption $1\frac{1}{2}$ cub. ft. per hour.)

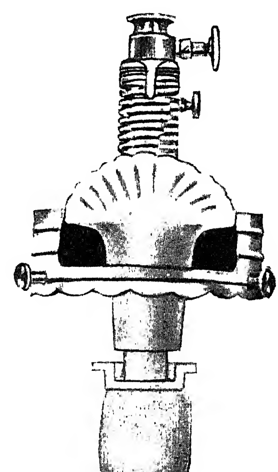


FIG. 19.—"Nico-vibra" anti-vibration device.

inverted burner the use of a special carrier to grip the mantle, which is not attached to the burner itself, is stated to be very

beneficial in prolonging the life of the mantle, since the shocks occasionally administered to the burner are not fully communicated to the mantle.

This last feature leads to the mention of anti-vibration devices, by which the burner and mantle are supported on springs, or some other resilient material. A typical device of this kind is shown in fig. 19, and a number of other well-known anti-vibration appliances are described in Mr Hole's well-known book on *The Distribution of Gas*. The Nico-vibra device has as its main feature a hardened steel spiral spring, which forms the outer connection between the burner and the nipple. If the burner receives a knock, it is merely displaced and then returns to its original position.

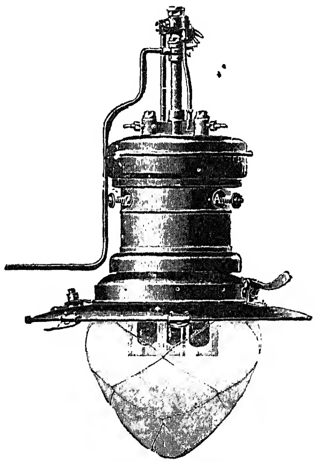


FIG. 20.—General view of Grätzin high c.p. low-pressure lamp (Candle-power 1000, consumption (approx.) 24 cub. ft. per hour.)

A special word or two may be said here on the subject of the latest types of high candle-

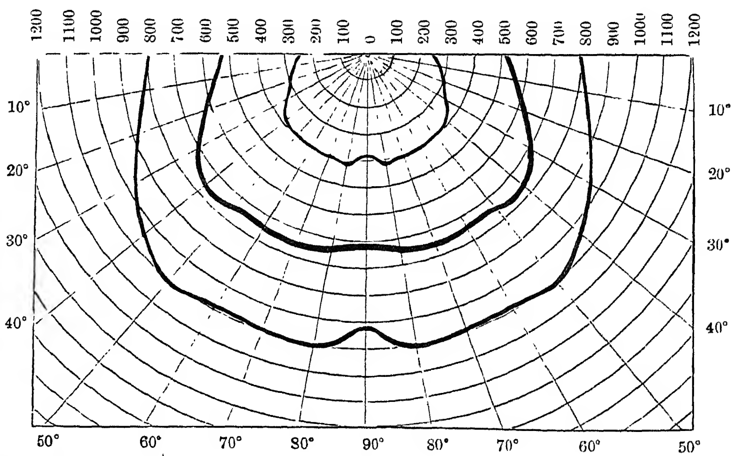


FIG. 20A.—Showing distribution of light from Grätzin low-pressure lamps, giving 300, 600, and 1000 c.p. with one, two, or three mantles respectively.

power low-pressure lamps. During the last few years a number of high efficiency inverted lamps of this kind have been introduced and have been utilised by the South Metropolitan Gas Co.

for lighting the streets in South London. Although these lamps are run on the ordinary mains, as much as 30 candles per cubic foot per hour is said to be obtained.

It appears that in the lamps of this kind issued since 1911 an even greater advance has been secured. Herr M. Scholz states that a low-pressure lamp, yielding about 40 candle-hours per cubic foot, has been introduced by Messrs Ehrich & Grätz in

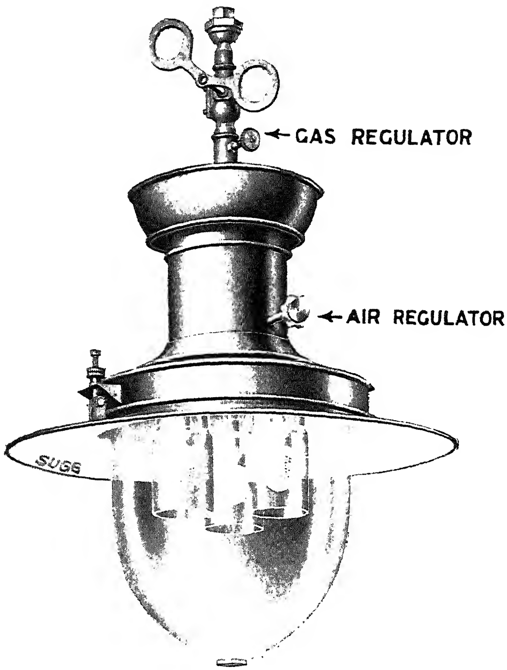


FIG. 21.—Showing Sugg high c.p. low-pressure "1911" lamp.

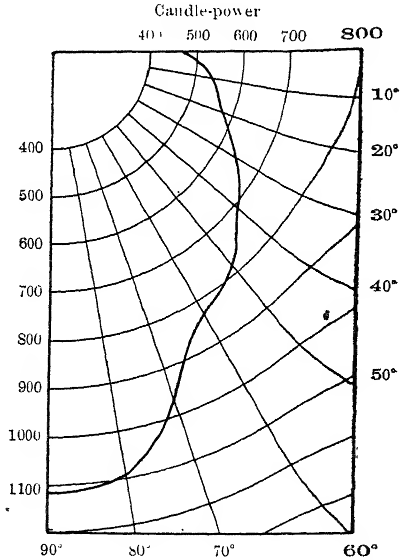


FIG. 21A.—Showing distribution of light from Sugg "1911" lamp.
(Consumption at 2 ins. pressure 18 cub. ft. per hour.)

Berlin; and several British firms, including Messrs Sugg & Co. and the New Inverted Gas Light Co., have since announced new models which, on a pressure not exceeding 20/10ths, are also said to yield a duty over 40 candle-hours per cubic foot.

By the courtesy of Messrs Ehrich & Grätz we are enabled to reproduce in figs. 20 and 20A a general view of the lamp and curves, showing the distribution of light with which it is credited. Figs. 21 and 21A refer to the Sugg "1911" lamp, the polar curve being again based on information kindly supplied by the manufacturers. It is interesting to notice that while approxi-

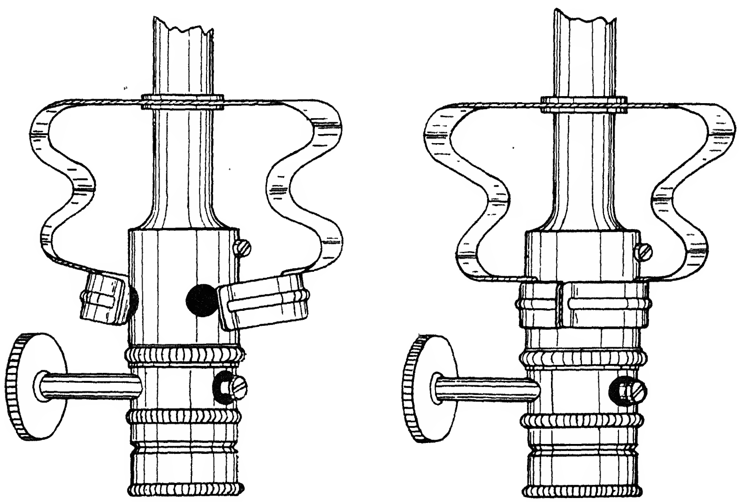
mately the same efficiency is claimed, the shape of the distribution curve of this last lamp differs considerably from that of Messrs Ehrich & Grätz. This appears to be due to the concentrating effect of the reflector in throwing most of the light downwards. Clearly a relatively small bend in the reflector might make a great deal of difference in this respect.

This improvement in efficiency is ascribed mainly to the judicious use of preheating, the passage of the gas over hot surfaces, and other improvements in the detail of the design of the burner.

Automatic Gas and Air Regulation.

It is well known that the best proportions of gas and air in a burner depend to some extent on the local pressure and the quality of gas.

This, and also the fact that the conditions change somewhat after a burner has become warmed up, led Whitaker and Little



Burner hot. Burner cold.

Fig. 22.—Showing action of Degea Airostat device.

in the United States to devise a form of thermostatic control of the admission of gas.[1] The arrangement is said to be of great assistance in counteracting any inclination to "light back." (In passing, it is interesting to note that Clegg, very early in the history of gas lighting, devised, in order to satisfy the fire

[1] *Trans. Illum. Eng. Soc. U.S.A.*, Dec. 1907.

insurance authorities, a self-closing burner with thermostatic action for the purpose of shutting off the gas whenever the flame became accidentally extinguished.) A thermostatic control is now employed in the Bland burners, and a similar device has also been employed in Germany by Herr Lebeis. Another apparatus is the Degea Airostat, shown in fig. 22. When the burner is cold the air-holes are almost completely closed by the metal collar, as shown on the right, but as it heats up the arms expand and the holes are gradually uncovered.

The improvements in inverted burners of late years have, however, gone far towards removing this difficulty, as they become warmed more rapidly and are not so readily subject to variations in quality of gas. A striking announcement was made by Mr Charles Carpenter at the meeting of the Illuminating Engineering Society in December 1910, to the effect that the South Metropolitan Gas Co. had successfully introduced a form of burner which is adjusted once and for all for the quality of gas on this company's supply area, and can therefore be used without means of gas and air regulation.

Inclined Burners, etc.

Before proceeding to the discussion of high-pressure lighting, a word or two may be said about several types of inclined burners which have been introduced of recent years.

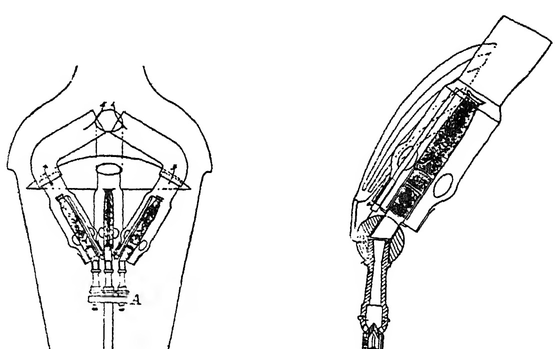


Fig. 23.—Greyson de Schodt inclined burner.

One such development was described by M. Greyson de Schodt before the Société Technique du Gaz in 1909. An advantage claimed for this contrivance is that the slope of the mantles can

be varied so as to alter the distribution of light, according to the nature of the street. One drawback to the use of horizontal and inclined burners (in addition to the difficulties connected with the deflection of the flame from its natural vertical position) is that the weight exercises a sideways thrust, since the centre of gravity falls outside the support for the mantle.

In the "Twin-light" burner the ingenious expedient was adopted of burning both an upright and an inverted mantle off the same supply.

Self-contained Highly Efficient Lamps.

We must next turn to the great developments in gas lighting which have been achieved by the aid of high pressure. But before doing so a few words may be said on a class of lamps which were designed to produce a more brilliant light than that obtainable with the ordinary low-pressure burner, and yet to be burned on the ordinary gas supply. A conversion to high pressure may affect the entire installation, whereas one often desires to have a high candle-power lamp only at one particular spot, and (in the absence of high-pressure mains from the company becoming available) to avoid the necessity of installing a special compressing plant.

Attempts were therefore made to introduce in gas lamps, burning on the ordinary supply, local pressure-raising or intensifying devices. Mr Scott-Snell many years ago devised means of increasing the output of light from a lamp by causing the waste heat to compress a supply of air, thus securing a forced draught.

Another example of this type is provided by the Chipperfield lamp, introduced a few years ago. In this case there is a reservoir into which, by the action of the heat, a supply of air was also pumped periodically and subsequently utilised to enable more perfect combustion to be secured.

In the Lucas and Welsbach-Kern self-intensifying and other lamps, a long chimney was placed above the burner, and this likewise promotes a strong draught, drawing in an increased supply of primary air and leading to improved combustion. Afterwards this form of lamp was modified by the ingenious application of the thermopile, the hot junctions of which were placed in the heated products of combustion. The cold junctions projected into the cool air outside the lamp and thus increased

the p.d. set up in the thermopile. The current generated was supplied to a small electrically-driven fan at the base of the lamp.

The comparatively complicated nature of the mechanism involved in many of the self-intensifying lamps led to certain difficulties; they were not always independent of temperature and weather conditions, and the working of the small hot-air engine for raising the pressure was not always as noiseless as might be desired.

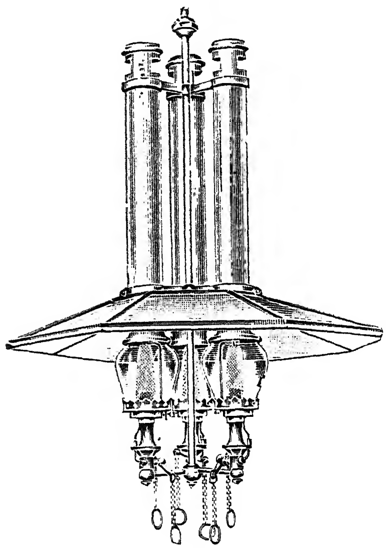


FIG. 24.—Lucas self-intensifying lamps; 3-light cluster.
(Candle-power 1200, consumption 30 cub. ft. per hour.)

In the most recent types of low-pressure high candle-power lamps, referred to on pp. 49–51, similar principles are in part employed with the object of securing a more intimate mixture of gas and air, and more perfect combustion, but the methods are more simple. The use of moving parts, pistons, abnormally long chimneys, etc., will no doubt eventually become obsolete, reliance being now mainly placed on the accurate design of the mixing chamber and gas and air inlets, and on the judicious use of preheating. As has been explained, there are a number of lamps now obtainable which will burn on an ordinary low-pressure gas supply, and without complicated mechanism, and yet credited with as high an efficiency as 30 to 40 candle-hours per cubic foot.

HIGH-PRESSURE GAS LIGHTING.

We now come to one of the most striking of all the recent developments in gas lighting, the use of high pressure. By this means a remarkable increase in efficiency can be secured, and the brilliant illumination of many of our main thoroughfares by this comparatively new method bears witness to the improvements in this direction which have recently been made.

During the last ten years, ideas as to the pressure which

could be conveniently employed in street mains have radically changed. In 1900 almost all the existing gas lighting in London was carried out with a comparatively low pressure, in the neighbourhood of 2 inches of water. In 1901 Blackfriars Bridge was being experimentally lighted with Sugg 300 c.p. lamps at a pressure of 10 inches of water; and in the same year a striking paper was read by Mr A. W. Onslow,[1] describing the high-pressure installation, using 54 inches, at Woolwich Arsenal. As a matter of fact, pressures in the mains of fifty inches are now frequently exceeded. For example, it is stated that in the recent high-pressure installation for the Dulwich covered tennis-courts, undertaken by the South Metropolitan Gas Co. (and now in some of the streets of London), as much as 80 inches was employed, while in Birmingham and elsewhere over 100 inches have been used successfully.

In a paper before the Sixth Annual Convention of the American Illuminating Engineering Society in 1912, Mr F. W. Goodenough gave some interesting information on the progress of the high pressure for shop lighting.

During the last few years there has been a great development in what is termed "parade lighting" systems. A few companies started the movement by making arrangements to supply a number of shopkeepers in one block of buildings with high-pressure gas, thus relieving the consumer from the necessity of installing a private compressing plant of his own. The maintenance is in the hands of the gas company, and an inclusive fixed price per annum is agreed upon. Such installations have rapidly multiplied. The Tottenham and Edmonton Gas Co. was one of the first companies to go into this on an extensive scale. The length of high-pressure mains for this purpose seems destined to make considerable progress, and to do away with the inconvenience of individual compressors.

High-pressure gas has naturally found its most prominent application in street lighting, where very powerful lamps are demanded. Thus the new Keith lamps employed in the City of Westminster are required to give from 2000 to 3000 candles, and lamps yielding to 4500 c.p. are now available.

In the high-pressure systems best known in this country it is the gas supplied to the burner which is compressed. There is, however, no inherent advantage in using high-pressure gas except for the purpose of producing a very intimate mixture of

[1] *Journal of Gas Lighting*, 19th Nov. 1901.

gas and air, and, simultaneously, a greater velocity of gas issuing from the burner. It is on these conditions, and the resulting high flame temperature, that the efficiency of high-pressure lamps is believed to be chiefly due.

Much has been written on the nature of combustion of the high-pressure flame and the theory of the high efficiency secured. On these points we will say a little more presently.

The discussion of the technical details of the many high-pressure systems—among which may be mentioned the Scott-Snell, Sale-Onslow, Tilly, Millenium, Grätzin, Pharos, Keith & Blackman types—would carry us too far afield. A word or two may be said, however, regarding the Keith & Blackman lamps, which are widely used in Great Britain, and which were exhibited and described by one of the authors in the course of a series of Cantor Lectures before the Royal Society of Arts in 1909.

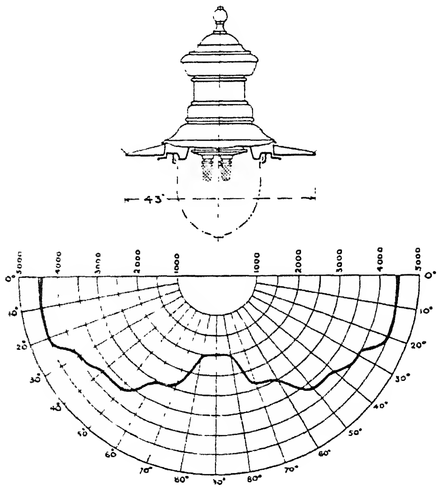


FIG. 25.—Sketch of Keith & Blackman high-pressure lamp, with polar light distribution.

The main advantage derived from these high-pressure lamps is of course the high efficiency, as much as 73·6 candle-hours per cubic foot having been obtained in some tests with ordinary town gas. However, 60 candle-hours per cubic foot is the value claimed in general by the makers. The lamps are made in all sizes from 60 to 1500 c.p. with single burners, and with multiple burners up to 4500 c.p.

The high efficiency is ascribed mainly to a preheating device, whereby the gas and air mixture is passed through a heater fixed on the bottom of the burner tube, as near the mantle as possible. It takes the form of two shallow cones, fixed base to base, with a diaphragm between at the outer edges. This has the effect of spreading out the mixture of gas and air over a large area of highly heated surface before reaching the nozzle. The heating of the gas and air mixture takes place progressively, for, as the mixture gradually moves forward, it is brought into

contact with surfaces that are more highly heated than those which it has just left. At the same time the heater has the effect of taking heat from the nozzle, and so prevents the temperature at its tip becoming too high. An additional effect is obtained by heating the secondary air supply before it comes in contact with the mantle. By these means as much of the waste heat as possible is utilised to give a regenerative effect. The high pressure used with these lamps (which may be 55 or even as much as 80 inches) is necessary in order to overcome the resistance experienced by the highly heated mixture in passing through the lamp.

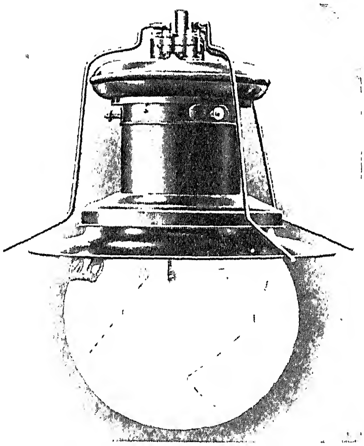


FIG. 26.—A general view of Grätzin high-pressure 4000-c.p. lamp. (Consumption (approx.) 60 cub. ft. per hour.)

Fig. 25 is a diagrammatic view of one of the latest forms of Keith lamps and the corresponding distribution of light. In fig. 26 is shown the latest type of high-pressure Grätzin lamp, which has been very largely utilised in Berlin and other German cities. Fig. 26A shows the distribution of light from the lamp as given by Herr M. Scholz, the curve being specially designed with a view to street lighting.

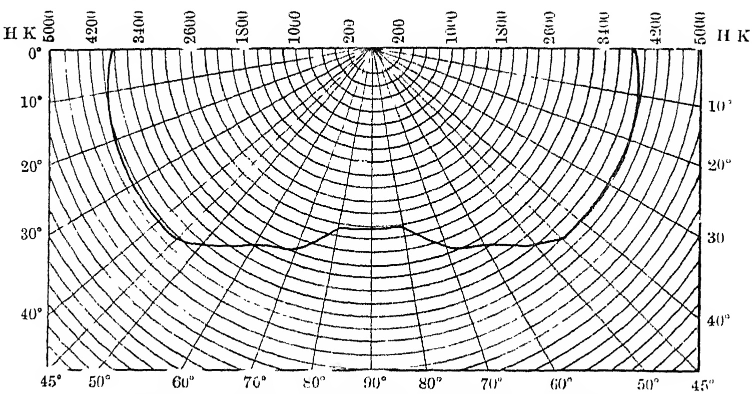


FIG. 26A.—Polar curve of light distribution of Grätzin high-pressure 4000-c.p. lamp.

At this stage it may be of interest to tabulate the efficiencies of the lamps referred to, and for this purpose we may reproduce the table in Mr Grafton's well-known book, merely adding thereto the values for the most recent high candle-power low-pressure and high-pressure lamps:—

Type of Burner.	Specific Comsumption (c.p. per cubic foot of gas per hour).
Flat flame, Batswing	4–6 (with 30-candle gas)
Ordinary Argand	2·7–2·9 „ 16 „
Standard „	3·2–3·3 „ 16 „
Albo-carbon light	5–6
Regenerative lamps	10–12
Welsbach "C" burner (1893)	12–14
„ „ (1898)	19–24
„ "Bansept"	16–20
Added :—	
Modern low-pressure inverted	20–25
Latest high c.p. low-pressure inverted lamps (1911)	35–40
High-pressure (50–80 in.)	60

This gives an excellent picture of the progress that has been made.

High-pressure Gas and High-pressure Air.

A short time ago there was an animated discussion in the gas journals in Great Britain and Germany regarding the comparative merits of high-pressure air and high-pressure gas.[1] Both systems are capable of producing a very intimate mixture of gas and air and the desired high flame temperature, and authorities seem now to consider that the efficiency attainable by the two processes is very much the same.

On the other hand, certain advantages as regards convenience have been claimed for the respective methods. For the high-pressure air system it has been pointed out that the ordinary gas-mains can be used, low- and high-pressure lamps being supplied from the same network, and that when a change to high pressure is made it is not necessary to alter the existing piping in any way; that no special meters are needed; that an escape of compressed air, unlike compressed gas, leads to no danger; and that, even should the pressure-air system fail

[1] *Illum. Eng.*, London, vol. i., 1908, p. 956; *Zeitschrift für Beleuchtungswesen*, 20th May 1908; *Gas World*, 20th May 1908; *Journal für Gasbeleuchtung*, Nos. 24 and 30, 1908; *Gas World*, 12th September 1908; *Journal of Gas Lighting*, 25th August 1908.

entirely, the lamps can still burn on the existing low pressure of gas, the light being diminished but not extinguished.

For high-pressure gas it has been claimed that the ordinary gas-pipes can often be used when a change to high pressure is made, whereas with high-pressure air it is always necessary to install a second set of pipes to carry the air supply; that with satisfactory workmanship it matters little whether the pressure is 2 or 50 inches, and in practice it has been found that accidents with high-pressure gas have not been more frequent, nor more serious in their results, than with a low-pressure, and that it can therefore be regarded as quite safe and practical. Occasionally local circumstances may tend to favour one system or the other. For example, Dr Göhrum,[1] in a recent article on the gas lighting of Stuttgart, states that he considered the advantages of the two methods pretty evenly balanced. In deference to an unjustified but keen apprehension of high-pressure gas on the part of the public, however, high-pressure air was adopted, and this step procured permission to install compressors in many convenient spots beneath schools, public buildings, etc., which might not otherwise have been granted.

The high-pressure air system seems to have found most extensive use in the hands of the Pharos Licht Gesellschaft, Germany; it is, however, of interest to recall that it was also used many years ago by the United Kingdom Lighting Trust in this country, and is still in use at the present day.

Compressed Gas and Air.

A few words may also be said about the Selas system[2] of compressing a mixture of gas and air, thus constituting a combination of the methods mentioned above. The gas, after passing through the meter, enters a mixing apparatus, from whence it emerges into the compressor and is delivered to the service-pipes at a pressure of 10 inches of water. At this comparatively low pressure the ordinary pipes can be used, and, owing to the fact that they contain a mixture of gas and air, the actual leakage at 10 inches would be no more serious than a similar leak with undiluted gas at 2 inches.

With this comparatively low pressure of 10 inches an

[1] *Jour. für Gasbeleuchtung*, 25th May 1911.

[2] See also a paper by Mr F. D. Marshall before the Institution of Gas Engineers in 1903.

efficiency as high as 50 candle-hours per cubic foot has been reached, and it is further claimed that this efficiency is obtained even with the smallest of the burners, which range from 25 to 5000 c.p.

Other Recent Improvements in High Candle-power Lamps for Street Lighting, etc.

Naturally the pioneering work done in Berlin and elsewhere on high-pressure gas street lighting was attended with difficulties. Drehschmidt[1] recalls that much time was devoted to the choice of a suitable mantle. Double webbing was originally used, but the life was exceedingly short—sometimes only a quarter of an hour. But the recent types of mantles for high pressure are a vast improvement. Thus Herr M. Scholz stated in 1909 that the average life of mantles used for public lighting in Berlin amounted to 200 hours,[2] and Mr Goodenough mentioned in his recent address to the Illuminating Engineering Society that in some districts in that city as much as 1000 hours is obtained with the latest uncollodionised mantles.

Another difficulty initially experienced in Berlin was that the original lanterns, containing two burners, were constantly breaking owing to the flame shooting out at the moment of lighting up; this was remedied by substituting three burners of somewhat smaller consumption.

The method of obtaining a given candle-power by using several mantles, rather than by a very powerful single one, has other merits. For one thing, a small mantle is on the whole less liable to injury and lasts longer, and it is possible that the shorter and more concentrated flame used may render it more efficient. Again, when three mantles are used the breakage of one is not so serious, since the remaining two mantles still enable the lamp to yield about two-thirds of its full light; but the breakage of a single big mantle might mean total extinction. It is also obvious that a lantern in which the mantle that deteriorates soonest is constantly being renewed will, on the whole, give a more uniform light than one containing a single mantle. For of the three mantles burning there will always be *one* which is comparatively new, but the single-mantle lantern

[1] *Jour. für Gasbeleuchtung*, 22nd Aug. 1908.

[2] See *Jour. of Gas Lighting*, 26th Oct. 1909; also *Illum. Eng.*, London, Dec. 1910, p. 736.

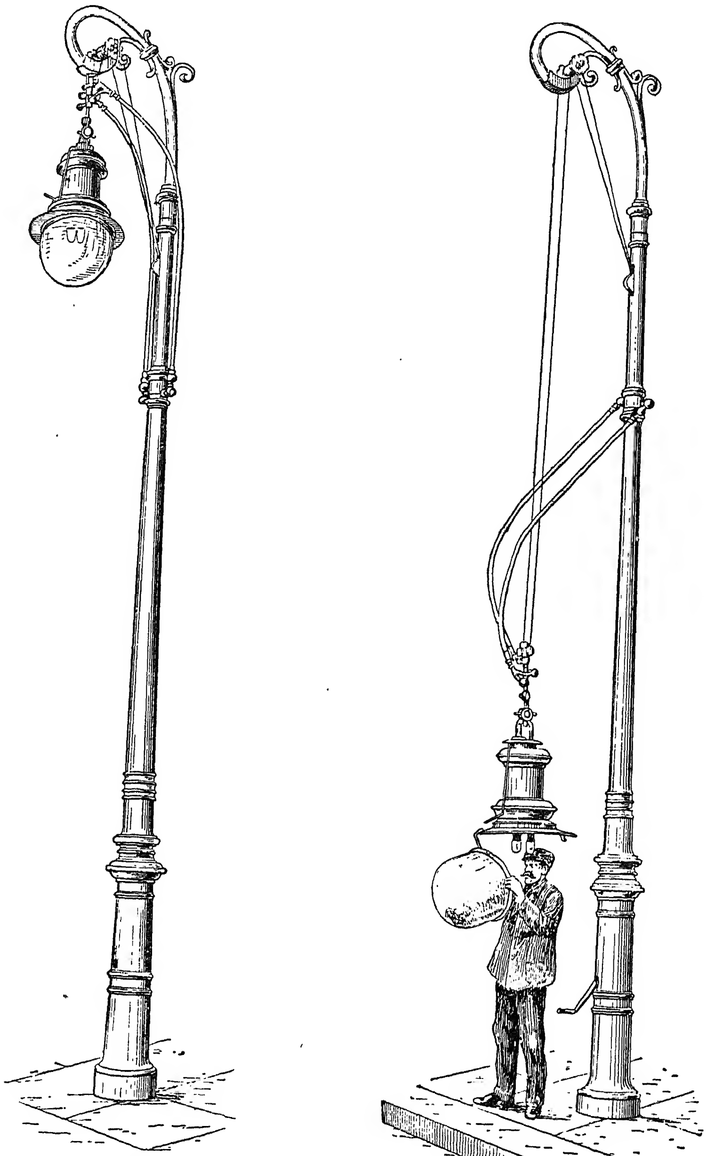


FIG. 27.—Showing lamp-post with gear, enabling high-pressure incandescent gas lights to be raised and lowered to receive attention in the streets.
(By permission of the Royal Society of Arts.)

must be allowed to go on burning until this one mantle has fallen to the permissible limit, and so requires removal. One other advantage of the multiple mantle system is that it is possible to arrange for the extinction of two out of the three mantles at a given hour of night, thus effecting a saving without plunging the town into complete darkness.

The visit to the Continent of the deputation appointed by the Streets Committee of the Corporation of London in 1906 brought

FIG. 28.—Showing Pharos high-pressure air gas lamps in a street in Stuttgart.

to the general notice an interesting innovation in gas street lighting. In the report of the deputation the suggestion was made that gas lamps should be suspended centrally in the middle of roadways on wires spanning the street, and equipped with raising and lowering apparatus in the same way as has been done in the case of arc lamps. This suggestion was then somewhat novel and gave rise to some surprise. The method had, however, been experimented with already by Messrs Ehrich and Grätz in Berlin; and shortly afterwards one of the writers, in visiting Stuttgart, had the op-

portunity of examining the well-known installation on these lines in that city. Fig. 27 shows the form of raising and lowering apparatus for use on ordinary side standards, first introduced by Messrs Ehrich and Grätz. It will be observed that two flexible pipes are attached to the mast, but only one of these is needed to convey gas. The lamp is raised and lowered by a double cord from below, but when hanging at rest (as shown on the post on the left) does not depend on this cord for its support. Specialprovision is also made to reduce the vibration due to winds, etc., to a minimum.

An arrangement for the central suspension of lamps is shown in actual use in a street in Stuttgart in fig. 28. Experience

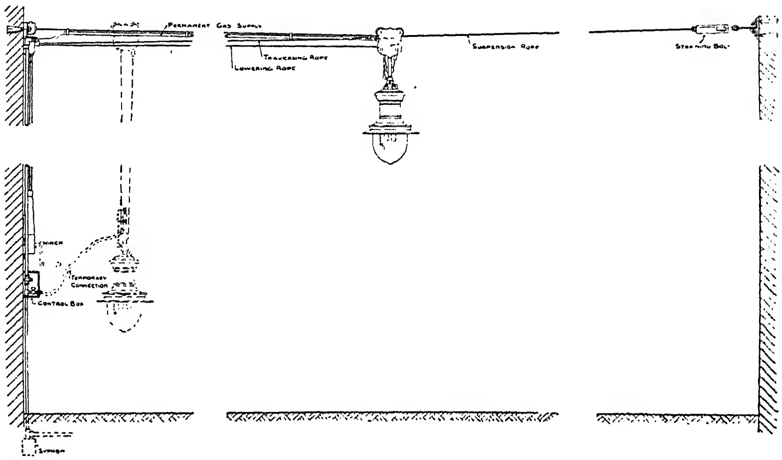


Fig. 29.—Showing Keith traversing and lowering gear. The lamp is shown in full hanging in the centre of the road, and it can be drawn to the side and lowered to receive attention, when it assumes the dotted position.

appears to have shown that jointed tube is preferable to flexible tubing, with a view to preventing leakage. Several installations have been installed in London and Manchester. At the end of 1911 the City of London resolved upon extensive improvements in their lighting, and decided to install about 40 centrally hung gas lamps of 2000 c.p. high-pressure type. In fig. 29 we are able, by the courtesy of Messrs Keith & Blackman, to reproduce their most recent gear for this purpose. It may be noted that their experience confirms that of Continental manufacturers in approving jointed instead of flexible piping.

Another novelty introduced by the same firm is the enclosure of the high-pressure mantle in a fused silica globe "a little

bigger than an ordinary tumbler."[1] By this method it is found unnecessary to admit secondary air, and the high flame temperature is said to enable a 10 per cent. increase in efficiency to be obtained. The reduction in bulk is very marked, and the saving in breakage of globes is expected to be considerable. A number of these lamps were displayed at the National Gas Exhibition at Shepherd's Bush in October 1913.

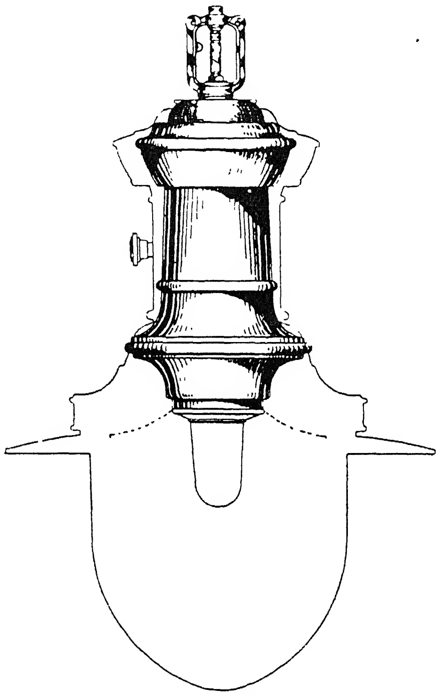


FIG. 30.—The new "Keith" 1500-c.p. gas lamp, with silica cup (one-sixth scale).

DISTANCE EXTINGUISHING AND IGNITION.

One great advantage enjoyed by electricity is the ease with which it can be switched on and off; lamps can be controlled from a distance, and, if necessary, lighted up from several separate places independently. That this is a considerable benefit in the case of indoor lighting will be readily understood. But in the case of street lighting it is also a great convenience to be able to control the lamps from the station and to light

[1] *Jour. of Gas Lighting*, 18th Jan. 1913, p. 454.

them up or extinguish them at any time just as the conditions of daylight demand. Naturally, therefore, attempts have been made to extend the same facilities to gas lighting.

In discussing the methods at present available we may draw a distinction between methods of lighting up which involve the use of a by-pass and those which are independent of this appliance. Naturally, the latter method is the most ideal in theory, but up to the present time it has proved more difficult to bring to a stage of absolute perfection. The majority of automatic methods in use demand a by-pass.

Pneumatic Control.—One of the earliest and simplest methods of distance control is the pneumatic. According to this method an extra tube of small bore is led to the burner. By merely pressing a plug switch at the end, a pulse of air is sent along the tube and operates a little lever turning on the full supply of gas. The simple mechanism in the burner is so designed that the next pressure of the switch can be made to turn off the gas, and so on. The method is simple and reliable. The tube, being very small, is readily concealed, and a lamp at a distance of 60 feet or more can be controlled.

The "Norwich" System.—Another system, the Norwich switch, is really an ingenious modification of the pneumatic principle, the pressure of the gas in the pipe taking the place of the pulse of air. No air-tube is necessary. The switch itself, in the form of a by-pass cock, is inserted in the supply-pipe leading to the burner which it is desired to control, and an automatic valve is applied to the nose-piece of the fitting. With the switch in its "off" position only enough gas passes to keep the by-pass alight. But when the switch is turned on, and the full gas pressure applied, this pressure actuates the mechanism in the nose-piece, opening a passage for the full supply of gas to the burner. When subsequently the switch is turned off, the passage is again closed and the by-pass only left burning.

In dealing with the lighting of large spaces, streets, etc., omewhat different conditions prevail, the chief of which being e longer distances at which it is desired to operate. In the se of a large district the time occupied by the lamplighter's uties is considerable, and the last lamp on his round would be ached half an hour or more after the first was lighted up. onsequently it was unavoidable either to arrange to commence ghting up somewhat before it was really necessary, or to allow e last lamps on the series to be lighted considerably later than

the proper period. Moreover, the sudden gathering of a fog, such as is still met with during the winter months in many large cities, taxed the capacities of the lighting-up staff, and the slowness of the process was a considerable drawback.

A method of control which has been applied in some cases is based on clockwork. For show-window lighting or advertisement signs, for example, a clockwork mechanism may be used by the aid of which, at a certain predetermined time, the gas is automatically cut off or turned on.

In the same way clockwork devices have been applied to street lighting. A mechanism of this kind was fitted to each lamp and set so as to turn on and off the public lamps according to the recognised lighting schedule during the year. The method, however, had certain drawbacks. For example, although, in a sense, an apparatus of this kind is very reliable, it has to be very accurately timed in order that all the lamps in a district may light up simultaneously. Moreover, the necessity of winding up the clockwork at periodical intervals and the cost were found disadvantageous. What, however, is perhaps the greatest drawback to clockwork control is that it acts independently of the climatic conditions. If, for example, the light fails early on an exceptionally dull day, the clockwork takes no account of this fact; and, again, if a fog comes on suddenly this is also ignored. Therefore, while clockwork control has proved its convenience for certain special fields (such as the control of show-window lighting), it is not now very generally used for public lighting in large towns. In country districts, where lamps are spaced a long distance apart, it may still be used.

The most usual modern method consists in the attachment to each lamp of a convenient form of apparatus which is not affected by the comparatively small fluctuations in pressure, such as occur on the network of a public gas supply under ordinary circumstances, but immediately responds to a sudden and deliberate rise in pressure beyond certain limits. What takes place, therefore, is as follows: As soon as the darkness begins to set in, the engineer at the gas-works raises his pressure for a short time—possibly several minutes. This wave of pressure rapidly spreads through the entire network and acts on all the mechanisms attached to the public lamps, causing them to light up; the extra impulse is then withdrawn and the pressure settles down again to its normal value. The automatic apparatus is so contrived that the next impulse, which of course is applied when

the time comes when lights are no longer required, causes the lights to be extinguished. There are a number of mechanisms of this kind now available, two of the best known types being the Rostin and the Bamag. The former utilises two valves floating in special non-freezing and non-evaporating mixture of glycerine and water. These valves can be so adjusted that the mechanism responds to any predetermined sudden pressure rise, but is not affected by small fluctuations. The Bamag system utilises the pressure of the gas on a regulated diaphragm, and this too can be set to respond to any given change in pressure; it can also be adjusted to be controlled either by a rising or a falling pressure wave.

These two devices may be regarded as typical of the two main classes of automatic pressure controllers. There are, of course, many others. For example, Stephenson described in 1908 the use of the Alder-Mackay apparatus in Tipton[1] with very satisfactory results, and Metzger has more recently given a most interesting account of his experiences in Bromberg with the Bamag and Meteor types.[2]

In this connection special mention may be made of another type of apparatus, the Automaton,[3] which is a combination of the clockwork and pressure-wave methods. The actual motive power required to actuate the mechanism (which has been found to vary according to the friction in the apparatus in different conditions of weather or the presence of vibrations, etc.) is not supplied by the gas pressure itself but by the clockwork mechanism. The rise in pressure merely sets the clockwork going—"pulls the trigger." It is claimed that the arrangement can be regulated with exceptional precision and that it is very little affected by variable friction. It can also be adjusted to work with either a rise or fall of pressure, may be set to respond to any required change, and is therefore readily arranged to comply with the pressure peculiarities of any district. It may also be arranged to turn off only one of a group of three mantles at the first impulse, to turn off another when the next impulse is applied, and to extinguish all three, if need be, with the third impulse.

Besides the advantages enumerated above, of enabling all the lamps in a district to be turned on or off practically simultaneously

[1] *Jour. of Gas Lighting*, 10th March 1908.

[2] *Jour. für Gasbeleuchtung*, 26th Aug. 1911; *Illum. Eng.*, London, Nov. 1911, p. 637.

[3] *Jour. of Gas Lighting*, 3rd May 1910; *Illum. Eng.*, London, vol. iii. p. 411.

at any moment from the gas-works, it is also stated that automatic control leads to an economy in several respects. There has been a great deal of discussion on these points during the last few years.[1] This is a highly technical subject, and the remarks made here must be regarded as only of a general character. For more detailed information the various references given below should be consulted.

The methods of automatic control so far mentioned demand the use of a by-pass, and therefore, although representing a great step forward, do not constitute automatic ignition in quite the same sense as switching on the electric light. A by-pass requires occasional attention to guard against the possibility of its becoming choked with dust. Again, if it is inadvertently blown out there will be a small but appreciable escape of unburned gas, which goes on continuously. The amount of gas taken by the pilot flame of an ordinary low-pressure indoor burner is generally taken at about one-fifth of a cubic foot per hour, although as little as one-tenth has been claimed in some cases. When this consumption is allowed to go on continuously throughout the day and night it may amount to a considerable amount per annum.[2] In the case of multiple unit lamps, improvements have recently been made in the direction of enabling a single by-pass to light up several burners, thus reducing the loss of gas to a minimum.

Electric Ignition.—We may next turn to an alternative method of automatic ignition, based on the use of electricity, in which a by-pass is dispensed with. The application of an electric current may be arranged both to cause the actual ignition and to turn the cock by electro-magnetic means.

Electric ignition systems may be divided into two distinct classes—those using a low voltage and commonly depending on the action of a heated fine wire, and those using high tension and employing a spark discharge. The former system has been used with the Keith lamps, and, by the courtesy of Mr George Keith, was first publicly exhibited by one of the authors at the Cantor Lectures of the Royal Society of Arts in 1909. We understand that experiments are still proceeding.

[1] See Stephenson and Metzger (*loc. cit.*). Also Dobert, *Jour. für Gasbel.*, 24th Dec. 1908, 30th Jan. 1909; Göhrum, *J. f. G.*, 28th May 1910; Brennecke, *J. f. G.*, 13th May 1911; *Jour. of Gas Lighting*, 29th March and 4th Oct. 1910, 30th May 1911, etc.; Seager, *Illum. Eng.*, New York, August 1909.

[2] See *The Railway Gazette*, 5th May 1911.

The well-known Telephos system also utilises the simultaneous control of the gas by electro-magnetic means and its ignition by a heated wire of special composition. Electric ignition on these lines is conveniently applied to lamps which must be placed out of reach in large halls, etc. It does not appear to have come into general use for street lighting. The supply of electricity may be furnished by a battery of dry cells, which, of course, run down eventually and require to be replaced. The dimensions and material of the glowing wire must be selected with care.[1]

The second electrical method of ignition is the so-called "jump spark" device.[2] The kindling in this case is accomplished by means of a high-tension spark discharge, the gas being turned on at the main simultaneously with the switch operating the electric current. The general method is to use a battery of dry cells, which feed a small induction coil. The wires from the high-tension side of the coil are led to the burners, and must be exceptionally well insulated owing to the high voltage of the current they carry. Neglect of this point has led to considerable difficulties with this method in the past, but it is now stated to be much more certain in operation.

In passing, it is of interest to note that these electric methods of gas ignition demand a combined knowledge of gas lighting and electrical engineering; there is no doubt that many of the failures of early devices were due to the fact that the inventors were not thoroughly conversant with *both* these subjects.

Lévy[3] describes an interesting modification of the high-tension method employed on the trains of one of the French railways. The source of current is in this case a hand-driven magneto machine, thus doing away with the necessity for a battery of dry cells, which require periodical renewal.

Self-lighting Devices.—Another class of automatic ignition devices which in theory approach closest to the ideal method of lighting up are those of the "self-lighting" class. It has long been known that there are materials which, when prepared in a very finely divided, spongy state, are raised to a comparatively high temperature when placed in a stream of gas. Indeed it is known that a mantle, or even a platinum wire which has been previously slightly heated, can be raised to incandescence under

[1] See Whitaker, *Trans. Illum. Eng. Soc. U.S.A.*, May 1910.

[2] Litle, Paper read at the Second Annual Convention of the Illum. Eng. Soc., U.S.A., 1908 (*Trans.*, Oct. 1908).

[3] *L'Éclairage à Incandescence par le Gaz* (Supplement), p. 44.

these circumstances. This is apparently due to the imperfectly understood process of "catalytic action," which, as we have seen, also plays a part in electric ignition by means of a heated wire.

The idea therefore occurred to inventors that this principle might be utilised to cause a stream of gas to light up automatically as it was turned on, and pellets of this spongy material were therefore prepared and suspended above the burner. The method is undeniably attractive, and devices of this kind were shown in actual operation at the gas exhibition at Earl's Court in 1906. The difficulty has been, however, that, although they acted very well at first, the pellets soon became uncertain in their action and eventually ceased to work altogether. This was found to be due partly to deterioration caused by the products of combustion, and in the "Conus" apparatus the active material was surrounded by an iron spiral with a view to screening it from these products. Other methods adopted have taken the form of arranging for the active pastilles, attached to fine wires, to be set in motion by the ascending columns of gas so as to swing out of the heated zone. Another plan has been to support the active material on rods of metals having a different coefficient of expansion, so that their distortion in the heat of the flame carried the pastille away from the heat. Grix,[1] in describing an apparatus of this kind, states that it was used for 67 days, on which 443 kindlings took place without any appreciable deterioration; this suggests that considerable progress towards permanency has now been made.

It is also of interest to mention that Fritsche[2] has suggested the combination of this method with pneumatic control, thus enabling a lamp to be turned on and off from a distance without the necessity for a by-pass or electric ignition.

The method has also been adopted of simply coating a small region of the mantle with active material. The latest forms of these self-lighting mantles are said to retain their qualities for several hundred hours or even for the whole of their normal life.

Pyrophoric Alloys.—There remains one development in methods of ignition to be mentioned, namely, the use of pyrophoric alloys. A summary of the present position has recently been given by Böhm.[3] Welsbach is generally credited with the

[1] *Jour. f. Gasbeleuchtung*, 31st Dec. 1910.

[2] Fritsche, "Pneumatische Gasfernzündung ohne Dauerflamme," *Jour. f. Gasbeleuchtung*, 6th Aug. 1910.

[3] *Illum. Eng.*, London, vol. iii. p. 503.

discovery that a mixture of iron and cerite gives forth sparks when rubbed, and the method has since been developed to a much higher state of perfection.

The pyrophoric alloy, it will be observed, takes the place of a match or taper. A small disc of the material is mounted in a convenient holder, and, by drawing back a lever, is briskly rubbed and caused to give off sparks; when applied to a stream of gas it causes it to burst into flame. Match-boxes have also been devised on the same principle and have found extensive use on the Continent, so much so that the Government in France (where matches are a State monopoly) actually put a tax on the competing pyrophoric articles. In these pocket contrivances the release of a spring causes the lid of the box to spring briskly open, rubbing the alloy in doing so, thus producing and igniting a wick which is moistened with petrol. It is very curious to observe that we have here a reversion to the old tinder-box, which was entirely superseded by matches, only to come into its own once more in the twentieth century.

An advantage claimed for the method is that it is a very safe means of ignition, seeing that it is distinctly difficult to set light to any solid material by the sparks. As at present used, however, it appears to be essentially a means of ignition, which is applied by hand and does not appear to have been experimented with to any great extent for distance control. Wunderlich,[1] however, has described the application of the method to a street lamp, the rubbing being accomplished by a special arrangement of levers operated from below.

Readers interested in the subject of distance control of gas-lights may be referred to a series of articles that commenced in the *Zeitschrift für Beleuchtungswesen* in 1909.

The question of the cost of different systems of lighting, properly speaking, does not fall within the scope of this work. Data on the subject are constantly published in the technical press. Readers may be referred to a prolonged discussion in the *Journal of Gas Lighting*.[2] In practice the choice of an illuminant is determined by many considerations quite apart from conventional table of cost, and such data should be used with some reserve.

[1] Wunderlich, *Jour. für Gasbeleuchtung*, 15th May 1909; see also *J. f. G.*, 1906, pp. 308, 400.

[2] *Jour. of Gas Lighting*, Nov. 21, 28, 1911, "Some Aspects of Lighting." See also *Competition Points for Gas Salesmen*, by A. F. Bezant.

Concluding Remarks.

Changes in the gas-lighting industry are occurring so rapidly that it is difficult indeed to forecast what the chief directions of progress in the next few years will be. It is clear, however, that there are quite a number of ways in which the luminous efficiency of existing lamps might be improved. The exact parts played by calorific power of gas, shape of flame, rapidity of combustion and flame temperature, preheating and the effect of hot surfaces on combustion have been discussed very fully,[1] and it is possible that when these effects are better understood very much more efficient illuminants (quite apart from possible improvement in the mantle) might be secured.

The almost universal adoption of the incandescent mantle throughout Europe has brought the question of the adoption of a calorific test, in conjunction with or even in place of an illuminating power, to the front, and it is now used by quite a number of the leading companies. The progress up to 1912 was summarised in a recent paper by C. O. Bond,[2] who has collected the opinions of various authorities in Europe and the United States on the subject; most of them appear to approve the calorific test in principle and state that it has made considerable headway in the larger cities. It may be recalled that Prof. J. T. Morris in 1908 carried out a series of tests on incandescent gas lamps,[3] and the apparent difference in the performances with different qualities of gas led him to lay special stress on the calorific test and gave rise to much discussion at that time.

If the prescribed illuminating power is reduced, and attention concentrated mainly on securing a high calorific value, a gas equally good for use with incandescent mantles may be produced, and the cost of manufacture might ultimately be sub-

[1] See, for example, Bunte, *Jour. of Gas Lighting*, 28th Sept. 1909; Bone, on "Surface Combustion, etc.," *Gas World*, 8th March 1909; *Jour. of Gas Lighting*, 6th Sept. 1910; *Trans. Inst. of Gas Engineers*, London, 1911; St. Claire Deville, *Jour. f. Gasbeleuchtung*, 21st Nov. 1909; *Illum. Eng.*, London, vol. ii., 1909, p. 451; Foreshaw, Inst. of Gas Engineers, London, 1909; T. Holgate, *Illum. Eng.*, London, vol. ii., 1909, pp. 457, 533, 615; Mayer, *Jour. f. Gasbèleuchtung*, 8th Oct. 1910, and other references in this chapter previously given.

[2] "A Survey of American Gas Photometry," Paper read before the St. Louis meeting of the American Gas Institute, *Prog. Age*, 1st Feb. 1912.

[3] "Tests of High- and Low-pressure Incandescent Gas Lighting," *Illum. Eng.*, London, vol. i., 1908, p. 627.

stantially lower. It is even conceivable that in the future it might be possible to make gas of a considerably higher calorific value than at present, and this might lead to a corresponding improvement in the light given by incandescent gas lamps. Mr W. H. Y. Webber has also suggested that in the event of cheap supplies of oxygen becoming available, a double system of oxygen and town gas for distribution might lead to efficiencies well over 100 candle-hours per cubic foot. It is evident, therefore, that the limits of improvement in the luminous efficiency of incandescent gas lamps are still far distant.

Another question that is constantly being raised is the "hygienic effect" of gas lighting. This may be taken to include not only the possible influence of products of combustion on the temperature, conditions of humidity and atmosphere of interiors, but also the effect of the illuminant itself on the eyes. Some careful inquiries into these subjects have been made.[1] The question is nevertheless still treated as an open one by controversialists, and it may be suggested that a full inquiry by an authoritative and impartial committee, on which representatives of the illuminants concerned and hygienic experts should be represented, would be helpful.

A feature of the development of the large gas companies during the past few years has been the spread of the principle of maintenance. There can be no question but that the majority of consumers do benefit by arranging with the gas company to undertake the upkeep of their lights. A company can naturally undertake the work more efficiently and more cheaply than a private individual can do. Only rarely is the average consumer willing or able to take sufficient trouble to maintain his burners in good condition, and he naturally lacks the technical skill of the gas-fitter in diagnosing defects. A big gas company, too, can naturally purchase mantles on a larger scale and at a cheaper rate than the small consumer can do, and, by regular testing, can ensure that the quality is up to the prescribed standard.

Another advantage enjoyed by the modern consumer is that when arranging for the supervision of his installation he can also avail himself of the advice of the company as to the arrangement of the lights. The leading gas companies are

[1] *E.g.* S. Rideal, *Proc. Roy. San. Institute*, March 1908; Toogood, *Medical Magazine*, Feb. 1911; J. Brearley, *Gas World*, 21st Nov. 1907.

already making a practice of encouraging the giving of such advice, and in the course of time will doubtless go still further towards the formation of illuminating engineering departments to assist consumers.

The study of the practical applications of gas lighting in streets, shops, factories, etc., is quite as interesting as the development of the lamps themselves. The design of appropriate globes, shades, and fixtures for specific purposes is also now being improved by the concerted efforts of the gas companies and the manufacturers, although much still remains to be done in this respect. With these matters we shall deal in later chapters.

An event of importance during 1912 was the organisation of the British Commercial Gas Association.[1] This Association is to deal mainly with publicity work, the organisation of exhibitions and displays, and the establishment of a central testing laboratory has also been suggested. It is hoped that the Association will be the means of bringing together all those interested in gas lighting, whether with the supply of gas or the sale of illuminating and heating apparatus. It should therefore be of considerable service to the lighting industry.

One other event of 1913—the National Gas Congress and Exhibition, held at Shepherd's Bush, London, in October—deserves mention. A full account of this exhibition, which in some respects presented quite novel features, has been published in several English journals.[2] One of the most interesting characteristics of the exhibition was the series of conferences on important industrial and scientific topics; at several of these conferences the discussion of illumination played an important part.

[1] See *Jour. of Gas Lighting*, Oct. 8, 15, 1913.

[2] *Illum. Eng.*, London, vol. vi., Nov. 1913; *Jour. of Gas Lighting*, Sept. 30, Oct. 7, 14, 21, 1913; *Gas World*, Oct. 4, 11, 1913.

CHAPTER III.

ELECTRIC LIGHTING.

The Physics of the Incandescent Lamp—Limitations of the Carbon Filament—Nernst, Osmium, Tantalum, Graphitised, Helion, and other Lamps—Tungsten Lamps: Methods of Manufacture, Efficiency and Life—Early Difficulties and Limitations—Use of Transformers, pairing and series-parallel devices—Use of low-voltage Lamps for Hand-lamps, Motor-car Lighting, Torches, Miners' Lamps, etc.—Modern high Candle-power Tungsten Lamps—The Half-Watt Lamp—The Arc Lamp—Flame and Impregnated Carbons—Luminescence—Deposit-Free Globes—Life and Efficiency—Magazine and Enclosed Flame Arcs—Arcs using Metallic Oxides—The Magnetite Arc—Miniature Arcs—Projection Arc Lamps—Vapour Lamps—Cooper-Hewitt Lamp and Fluorescent Reflector—"Orthochromatic" Tungsten and Mercury Lamp Combination—Quartz Tube Mercury Lamp—The Moore Light—Neon Tubes—Other Recent Improvements.

DURING the last twenty years remarkable advances in electric lighting have been made. In this chapter only a sketch of some of these developments can be given. The reader may be referred to several recent books[1] for fuller details on the subject, and also to many articles to which allusion will be made in due course.

INCANDESCENT LAMPS.

The commercial incandescent lamp is generally regarded as the simultaneous invention of Swan and Edison about 1879. At first it was not attempted to make high-voltage lamps. The transition from 100 to 200 volts to meet the requirements of the station engineer proved a matter of some difficulty, and it was some time before the life and efficiency of such lamps approached those obtained with the low-voltage type. But a steady improvement in quality took place, until a life of 800 hours was ultimately attained and the original specific consumption of 5 watts per candle eventually reduced to 3·5.

It may seem singular that for twenty years the actual

[1] *Electrical Lamps*, by Maurice Solomon; *Elektrische Beleuchtung*, by B. Monasch; *Electric Illuminating Engineering*, by W. E. Barrows.

construction of the incandescent lamp should have remained practically the same, especially to those who have viewed with amazement the extraordinary progress of the last few years. At first sight, indeed, this recent progress appears very sudden, yet it was not really so. As Professor Blondel has pointed out in a recent very able review of this subject,[1] a considerable amount of unsuccessful pioneering work on metal filaments was done by early investigators. It is only recently that the chemist has succeeded in bridging the gaps in our knowledge regarding materials for incandescent lamps, and in bringing these substances to the requisite state of purity.

There is, of course, no physical impossibility in making a carbon filament burn at a consumption of 2 or even 1 watt per c.p.—for a short time. All that is necessary is to "overrun" the lamp by applying to it a pressure considerably in excess of that for which it is intended. The filament will then receive an abnormally high current and will glow more brilliantly. Unfortunately, however, it will only do so for a very limited time, for under these circumstances the carbon filament vaporises, blackening the bulb and disintegrating very rapidly. It was therefore assumed that what was necessary was to find a refractory material with a very high melting-point, and, as a matter of fact, the earliest attempt at improvement on the carbon filament lamp—the Nernst lamp—was a step in this direction.

Now, a high melting-point may be a desirable quality in a filament. Yet it is now recognised that this slow volatilisation of incandescent carbon becomes evident at a temperature far below the estimated melting-point. It appears, then, that it is mainly this slow preliminary volatilisation that we must endeavour to avoid. The success of the more durable filaments now available seems to be due largely to their good qualities in this respect. They can be run at a temperature considerably above that utilised in the carbon-filament lamp without undergoing deterioration to anything like the same extent.

An interesting review of possible materials for the manufacture of glow-lamp filaments was given by Mr J. Swinburne in a paper before the Institution of Electrical Engineers in January 1907. As mentioned previously, the possibility of using certain metals had occurred to several early experimenters in this field. Yet the inclination to search for more refractory materials than carbon finally led in the opposite direction, a material which was

[1] Paper read at the International Electrical Congress in Marseilles, 1908.

actually a worse conductor of electricity than carbon being utilised in the Nernst lamp.

The Nernst Lamp.—The Nernst lamp, which was introduced about 1897, deserves the credit of being the first practical attempt to substitute some other incandescent substance for carbon. The actual filament consisted of a rod composed of certain rare oxides (zirconia, yttria, erbia, etc.). In the cold state this rod is non-conducting, and it was therefore necessary to introduce into the lamp a subsidiary heating coil which warmed it up sufficiently for conduction to begin, causing the lamp to light up. When this occurred the heating coil was automatically cut out of circuit by a small electro-magnetic arrangement, usually mounted in the holder of the lamp. It was also found to be necessary to compensate for the extreme sensitiveness of the filament to change in pressure by placing in series a special iron-wire steadying resistance.

It was found possible to make lamps which would run, with a consumption of only about 1·5 to 2 watts per c.p., for a life of over 400 hours—a remarkable advance beyond the greatest efficiency attained with carbon filaments. In the case of high candle-power lamps even better efficiencies were attainable.

The lamp, however, was subject to certain disadvantages, which have led to its being superseded by the newer metallic-filament lamps. Its complexity is inconvenient, and the number of component parts increases the possibility of failure. Another drawback is the fact of its being necessary to wait for at least 10 to 15 seconds while the filament is reaching a conducting state before the lamp lights up. In addition, the Nernst lamp was not recommended for use on alternating current circuits.[1]

The Osmium Lamp.—The Osmium lamp was introduced about 1898 by Auer von Welsbach, the inventor of the incandescent mantle. The lamp is now chiefly of interest historically as the first practicable metallic-filament lamp of recent date. Its development was hindered by various difficulties in the manufacture, including its brittleness and inability to make lamps for higher pressures than fifty volts. The metal osmium has been superseded by other more convenient and cheaper materials to-day.

Iridium and Zirconium Lamp.—Experiments have been made with these metals. They have been confined chiefly to

[1] For a detailed account of the theory of the Nernst lamp see *Electric Lamps*, by Maurice Solomon, chap. vi.

filaments of low voltage for motor vehicles, etc., and, like the osmium filaments, have now been practically replaced by tungsten lamps.

The Tantalum Lamp.—The Tantalum lamp was first introduced by Messrs Siemens Bros., as a result of the researches of von Bolton. As the name suggests, the filament is composed of the metal tantalum, in the form of drawn wire. The consumption of the lamp varies from about 1·6 to 2·2 watts per candle, according to circumstances, and the life is generally given as about 800 hours.

The fact of drawn-wire filaments being used has been a great advantage as regards durability, for the filament can be wound on a spiral, and, owing to its ductile nature, is not easily damaged by shock.

One disadvantage of the tantalum lamps is that the results on alternating current are apparently not so satisfactory as on direct current circuits. The alternating current has the effect of causing filaments to become crystalline, and so assume gradually a curious disjointed condition which shortens their life. This effect has been studied by Scarpa[1] and others. According to one theory the crystallising phenomenon is due to the continual trembling caused by the attraction of adjacent filaments on one another.

Graphitised Filaments.—A remarkable development in incandescent lamps, which would have no doubt received much greater attention had it not been for the coming of the more efficient metallic filaments, is the graphitised filament used in the "Gem" lamp and developed in the United States as a result of the researches of Mr Howell.[2] Filaments so produced give a satisfactory light with a consumption of only 2·5 to 3 watts per candle. The life of these lamps is given as 1000 hours, and the fact of their being manufactured for high voltage and low candle-power was a great advantage. Moreover, the filament is little longer than the ordinary carbon one.

Various forms of Lamps.—Before proceeding to the so-called tungsten lamp, a brief reference may be made to several attempts in other directions which constitute interesting departures but have not yet led to commercial results.

Carbon filaments, composed of special homogeneous soot, produced by the carbonisation of vegetable oils, Chinese ink, etc.,

[1] *Atti della Assoc. Elettrotecnica Italiana*, Jan.–Feb. 1909.

[2] *Proc. Am. I. E. E.*, xxiv. p. 617, 1905.

have been made by certain German inventors.[1] Their experiments led them to expect a useful life of 1000 hours with a consumption of only 1 watt per candle. These researches are interesting in view of the fact that some authorities are still inclined to think that the incandescent lamp of the future may utilise an improved form of carbon filament.

An attempt has been described by Hopfelt [2] to improve the efficiency of carbon filaments by burning them in an atmosphere of mercury vapour. It is claimed that the high pressure of the latter reduces the tendency to disintegration on the part of the filament and enables the lamp to run at a consumption near 1·5 watts per candle. A complete study of these lamps has been published by U. Bordoni, who found, however, that the samples examined had but a small life.[3]

Another departure which has attracted much attention is the Helion lamp brought out by Parker and Clark in the United States. The filament of this lamp is supposed to consist mainly of silicon, which is deposited by a special method on a carbon core.

For this lamp it is claimed that a life of over 1000 hours, at an efficiency of 1 watt per candle-power, coupled with practically no diminution in intensity, is obtained; at the same time all the advantages of a high-resistance filament are said to be secured. But the lamp has not yet been introduced commercially.[4]

Tungsten Lamps.—We now come to the most widely known form of metallic-filament lamp of the present time—that utilising a filament of tungsten. There are very large numbers of such lamps on the market called by different names and made by several distinct processes. The materials used are believed to be subject to slight modifications in the case of different firms, but it seems that the metal tungsten is the chief ingredient. A very large number of patents has been taken out in this field, and the processes of manufacture are too complicated for anything but a very brief reference here. Readers interested in the matter may be referred to the papers by Professor Blondel [5] and the recent work by Maurice Solomon, and to the articles by H. Weber and Dr Jacobsohn [6] in *The Illuminating Engineer.*

[1] Ritterburg and Hermann, *Zeitschrift f. Beleuchtungswesen*, 30th Dec. 1908.
[2] *Elektrotechnische und Zeitschrift*, vol. xxix., 8th Oct. 1908, p. 994.
[3] *Atti della Assoc. Italiana*, March–April 1909.
[4] *Elec. World*, 5th Sept. 1908.
[5] *Loc. cit.*
[6] *Illum. Eng.*, vol. i., 1908, pp. 297, 395, and 463.

Some information will also be found in the newly published work on *The Development of the Incandescent Electric Lamp* by Mr G. B. Barham.

A recent advance—the first firm to adopt it in this country being the British Thomson-Houston Company—consists in drawing out tungsten wire in the same manner as the tantalum filament. Lamps made on this principle are now supplied by several firms. By this method a very substantial gain in strength and durability appears to be obtained.

By using the metal tungsten a consumption, under favourable conditions, of only 1·1 to 1·2 watts per c.p., and a life

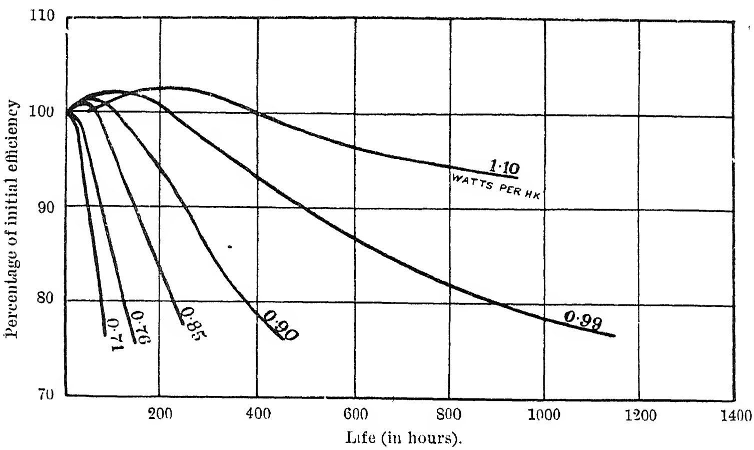


FIG. 31.—Showing useful life of tungsten filaments at various specific consumptions (Remané).

exceeding 1000 hours, may be obtained. It may be said, however, that it is not always possible to secure quite such good results as these in practice.

As was explained previously, there is no actual difficulty of obtaining a consumption of even less than 1 watt per c.p. in the ordinary carbon filament, but, as a result, the reduction of the life of the filament is so great that it is impracticable to do so. Fig. 31, which is based upon some results published by Remané,[1] shows the life obtainable at that date from tungsten filaments run at various specific consumptions. Somewhat better results have doubtless been secured since then, and, as will appear shortly, we are now promised special high candle-power lamps, consuming only half a watt per candle. But as yet it

[1] Paper read before the Verb. deutsch. Elektrotechniker, 1908.

does not seem possible to produce lamps of small candle-power with such an efficiency as this.

The fact of a metal being used instead of a non-metal for the manufacture of these filaments gives rise to several peculiarities. In the first place we find that the change in light caused by a certain percentage change in pressure is distinctly less; whereas a change in voltage of one per cent. brings about an alteration of 6 to 7 per cent. in the light from a carbon filament, the corresponding change for a metallic filament would only be about 3·5 to 4 per cent. Fig. 32 summarises the results obtained by various authorities on this point.

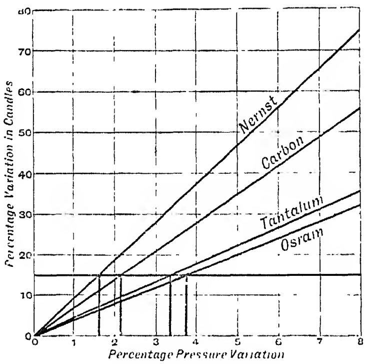


FIG. 32 —Variation in candle-power due to a given variation in voltage for carbon, Nernst, and metallic-filament lamps.

(Bohle, *Illum. Eng.*, London, vol. i. p. 387.)

Another consequence of using a metal filament is that the resistance when hot is considerably greater than when cold, whereas with a carbon filament the reverse is the case. As a result, there is a sudden rush of current (in some cases apparently as much as eight times the normal value) when the lamp is switched on. The filaments must therefore be stout enough to withstand this high momentary initial current; otherwise the lamp tends to burn out at the instant of switching on. This is one factor that makes it difficult to manufacture lamps of high voltage and low candle-power.

The process of making tungsten filaments was at first beset by many difficulties, and remarkable perseverance and skill has been exercised in overcoming them. Most of these obstacles arose through the fact of the material having such a low electrical resistance in comparison with carbon. In order to make lamps which would consume a reasonably small current on the ordinary pressures in use, it was necessary to employ both a very thin and a very long filament. For example, the production of 110-volt 25-c.p. tungsten lamps required a filament only 0·03 millimetre in diameter, whereas the corresponding carbon lamp would have a filament 0·15 mm. thick.

At the present time lamps taking 240 volts, and stated to

consume only 20 watts, are on the market, and the filaments are thinner even than the above.

Naturally, the first lamps proved to be extremely fragile and frequently broke in transport, but these difficulties have now been overcome to a large extent, and the new drawn-wire process seems to give a still stronger lamp.

There were other obstacles. For example, it was highly inconvenient to mount such a long length of filament within a bulb of reasonable size, so that the lamps first put upon the market, and especially those for high pressures, were undesirably long. Again, it was found that they could only be used in hanging vertical positions; otherwise the hot filament tended to sag and ultimately to short-circuit.

In addition to these defects, it was at first only possible to make lamps for low voltages. At a meeting of the Royal Society of Arts on 7th Feb. 1906, a metal-filament lamp, giving 30 candles and working at 37 volts, was shown publicly by one of the writers for the first time in England. In spite of the low voltage for which it was made, this was considered a remarkable advance, and the possibility of a metal lamp consuming only about 1·2 watts per c.p. came as a revelation. It was considered highly improbable that such lamps could ever be made for 200 volts. Yet only one year afterwards, at a meeting of the Institution of Electrical Engineers on 10th Jan. 1907, a 32-c.p. 220-volt lamp was shown by one of the writers.

Again in 1909, in the course of the Cantor Lectures before the Royal Society of Arts, it was mentioned that 100-volt tungsten lamps had already been produced in the United States, and a 100-volt 16-c.p. lamp followed shortly after. To-day 200-volt 20-watt lamps are actually on the market.

This gradual transition from low voltage high candle-power to high voltage low candle-power has, on the whole, been very fortunate for the electric lighting companies. For had it been possible for everybody to obtain the same light as before, with, say, one-third of the current, the sudden reduction in revenue would have been a very serious matter.

Before it was possible to obtain high-voltage lamps of moderate candle-power, other somewhat inconvenient expedients were adopted. For example, it was usual to "pair" lamps, *i.e.* to install two 100-volt lamps side by side in series on a 200-volt circuit. Even now, when high-voltage lamps are available, this method is still sometimes met with. It has, however, some

distinct disadvantages. When one lamp gives way the consumer is not, as a rule, careful to select another one of identical make and consumption to replace it. The consequence is that one not infrequently sees one lamp burning very brightly and the other very dim, and this naturally leads to premature breakdown.

The need for such expedients is now passing away, but it is still true that a 100-volt lamp will in general give better results than 200-volt lamps of the same consumption. The useful life will be better and the filament stronger. It will also usually be found that these high-voltage low candle-power lamps work at a consumption nearer 1·5 than 1·2 watts per candle. When alternating current is available, the use of a transformer is still advantageous in many cases. For example, on a 240-volt circuit one transformer stepping down to 50 volts may be used for a single house or even for a group of houses. Small transformers have sometimes been built into a chandelier, and even into a lamp-holder, in the manner shown in fig. 33. Quite recently Professor Ashton has advocated the use of a condenser instead of a transformer on alternating lighting current circuits.[1]

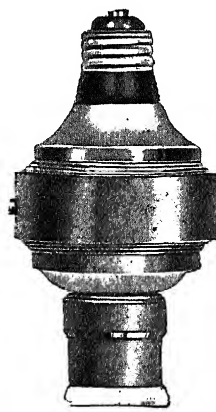


FIG. 33.—Small transformer built into lamp-holder for use on an ordinary alternating supply.

Transformers are particularly applicable to illuminated signs. For in this case all the lamps of which the sign is composed are switched on together, and the transformer need therefore never be running on light load. M. Weissman has devised an ingenious method of using small-voltage lamps for signs even on a continuous current circuit. Lamps are arranged in series-parallel. In these circumstances, if one lamp gives way an extra current merely flows through the adjacent lamps and the current is not in any way interrupted.

The ease with which low-voltage metallic-filament lamps can be manufactured has proved of great assistance in connection with the lighting of motor cars. Miniature carbon-filament lamps for such pressures as 4 to 16 volts were not very successful, owing to the very short length of filament that had to be used. But the low conductivity of the metallic filament is here a

[1] Paper read before the Institution of Electrical Engineers, May 1912.

distinct advantage, and within the last few years there has been almost a revolution in electric lighting for motor-cars vehicles. Even the pocket battery "torch" has become quite a practicable device; and portable hand- and miners' lamps, fed by a small battery, are now very usual. As an instance of the vogue of electrical miners' lamps, it may be mentioned that in 1912 the Home Secretary in Great Britain organised a competition for the best lamp of this kind, prizes to the value of £1... being awarded.

The metallic-filament lamp has proved to have distinct advantages in the opposite direction. While it is difficult to make high-voltage low candle-power lamps, it is much easier to make high candle-power units than in the days when only carbon filaments were available. Tungsten lamps yielding 500 and even 1000 c.p. are already on the market, while the 200-c.p. lamps have been most serviceable in providing a unit intermediate between the carbon-filament lamp and the arc lamp. The fact of being able to obtain these high candle-powers with a moderate consumption, and without its being necessary to give any attention in the form of renewing carbons, as in the case of arc lamps, has led to these lamps being largely used for display purposes and for side-street lighting.

A distinct stimulus has also been given to indirect lighting, since the inevitable loss of light by absorption is now of less moment. It may be mentioned also that in these high candle-power lamps the tungsten filament burns under exceptionally favourable conditions. According to Libesney, it has now been found possible to secure a life of 1200 hours with a consumption of only 0·85 watt per candle (Hefner). Until recently the life of a lamp running under these conditions would have been little more than 100 hours.[1]

The coming of the metallic-filament lamp has also been the means of stimulating an interest in illuminating engineering. In the first place, the gain in efficiency has led people to acquiesce in the desirability of effective shading, since the small loss of light so occasioned is now of less consequence. Then, again, it is recognised that the distribution of light from the tungsten filament, in its usual shape, makes some form of shade, globe, or reflector a practical necessity in order to direct the light where it is needed. Figs. 34 and 35 illustrate the comparative distribution

[1] Paper presented before the Vereinigung der Elektricitätswerke, Magdeburg, June 1911.

tion of light from a carbon-filament and a tungsten-filament lamp. Although in the case of the carbon lamp only about 40 per cent. of the horizontal candle-power is received immediately below the lamp, where it is mainly required, the percentage of the light so received is far less in the case of the metallic filament. A third circumstance working in the same direction is the fact of the brilliancy of the tungsten filament being so much greater. This has served to drive home the principle (which really applied to carbon filaments to a lesser extent) that the best results are obtained from incandescent lamps when they are provided with an appropriate globe or reflector, screening

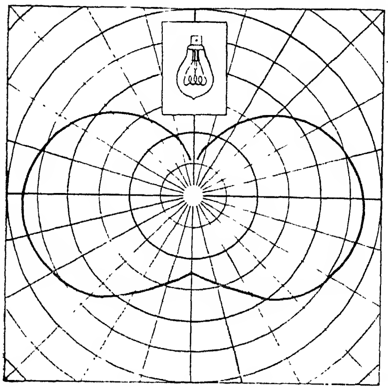


FIG. 34.—Distribution of light from carbon filament.

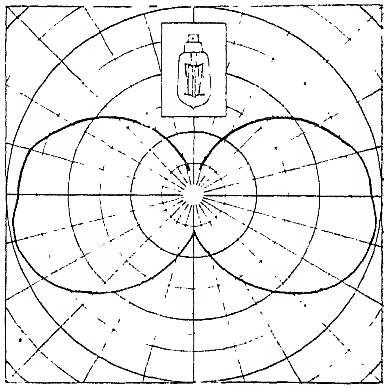


FIG. 35.—Distribution of light from tungsten filament.

the actual source from the eye and directing the rays of light where they are most needed.

[Since the above words were written, it has been found possible, by a new departure in the design of metal-filament lamps, to make high candle-power units of 300 to 3000 c.p., consuming only 0·5 watt per candle. The life is anticipated to be 800 hours. The filament is wound in a compact stout spiral, which glows not in vacuum but in an atmosphere of inert gases. Nitrogen appears to be mainly used at present, but it is possible that other gases, such as argon, may prove advantageous. It appears that by this means the rate of volatilisation of the filaments can be much impeded. Another device which helps to check the diminution in candle-power is the use of convection currents, which carry away the particles emitted from the filament, causing them to deposit in the neck of the lamp, where the

blackening has little obstructive effect on the light. The bulbs carrying these filaments have a long glass neck, so that the filament is a considerable distance from the cap. The obstruction of the latter is therefore small, and the polar curve with the usual form of bunched-up filament would approach nearer to the circle. With stout filaments of this kind it should not be difficult to obtain what is practically a "point source." It is understood that low-voltage half-watt lamps of small candle-power could be constructed, but it will probably be some time before such lamps are available at ordinary pressures. Meantime, it seems probable that history will repeat itself, and that on alternating circuits small transformers may come into use, just as in the early stages of the ordinary tungsten lamps. This method might have advantages for some special classes of work, *e.g.* for cinematograph lamps, etc.

It is too early as yet to speak of the future of these lamps, but there seems little doubt that, if expectations are justified, they will have a great influence on many fields of lighting.]

Arc Lamps.

The arc lamp is essentially a more complicated apparatus than the incandescent lamp. Possibilities of improvement lie not only in the manufacture of the actual light-giving agents, the electrodes, but in the design of the regulating mechanism as well. This last section of the subject cannot be discussed in any detail in the space at our disposal. Readers may be referred to several works that have recently been published dealing more or less fully with modern arc-lamp mechanisms.[1]

Until quite recently the arc lamp, like the incandescent lamp, seemed to have reached its final stage of development. A choice was available of two forms of lamps respectively of the "open" and "enclosed" type. Both utilise electrodes consisting of more or less pure or only slightly "treated" carbon. In both cases a compromise between two conditions had to be made. In the open arc lamp no restriction was placed on the access of air to the carbons, which therefore burned away somewhat rapidly, but yielded a correspondingly high luminous efficiency. Under favourable conditions a consumption of energy of only 1 watt per mean spherical candle-power could be obtained (with a clear

[1] *Das Elektrische Bogenlicht*, by W. B. v. Czudnochowski; *Electric Arc Lamps*, by J. Zeidler (1908); *The Application of Arc Lamps to Practical Purposes*, by Justus Eck (1910).

globe), but it was difficult, without special and somewhat cumbersome contrivances, to design a lamp which would burn for more than about 10 to 15 hours without it being necessary to renew the carbons.

In the case of the enclosed arc lamp the arc burns in a confined space, so that fresh air does not readily get access to the carbons and their oxidation is reduced to a minimum. Such lamps will burn for 100 to 150 hours without recarboning. This improvement in the life of the carbons, however, naturally leads to a certain sacrifice of efficiency, which is augmented when an outer globe is used in addition to the inner one enclosing the carbons. The specific consumption of such lamps may be as much as 1·5 to 2 watts per c.p.

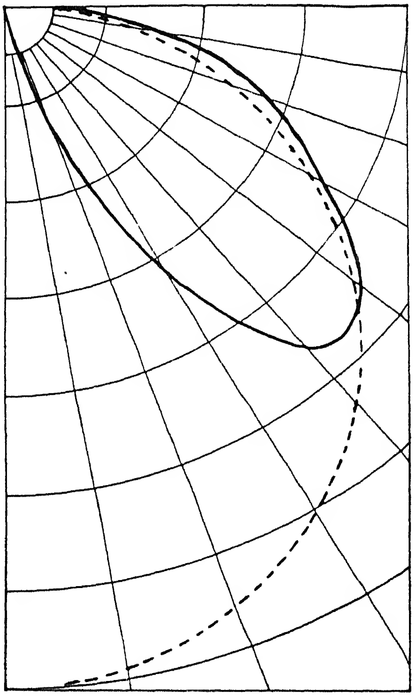


Fig. 36.—Curve showing maximum distribution of light from ordinary d.c. arc (Trotter).

Until recently all commercial arc lamps utilised vertical carbons, one above the other. In the arcs referred to the greater part of the light comes from the incandescent carbon, in a manner very fully described in Mrs Ayrton's well-known work on this subject.[1] When an alternating current is used a brightly incandescent spot is formed on both carbons. With a continuous current, on the other hand, the great majority of the light comes from a vividly incandescent spot termed the "crater" at the extremity of the positive carbon.

It was shown long ago by Mr A. P. Trotter[2] that the explanation of the shape of the polar curve lay in the shadow cast by the negative carbon. But for this, the curve would be approximately a circle, as shown in fig. 36, and the maximum intensity

[1] "The Electric Arc," by Mrs Hertha Ayrton.

[2] *Proc. Inst. Elect. Eng. London*, vol. xxi., 1892.

would be immediately below the arc. In consequence of this property of the direct current carbon arc it has been usual in practice to adopt either of two methods. We may make the positive crater the upper one, so as to direct the great majority of light downwards. This is, of course, the more general plan. Or, as an alternative, we may deliberately put the positive carbon underneath in order to direct the light upwards on a white diffusing surface, such as the ceiling of the room, whence it is reflected in all directions. This constitutes the so-called "indirect" system of lighting. The formation of a crater on the positive carbon is also a great advantage when an arc is used for lanterns and projection purposes—so much so that when only alternating current is available it is customary in the case of cinematograph entertainments to introduce a motor generator in order to transform to continuous current. Apart from this the alternating current, in leading to the successive formation of a crater on each carbon in turn, causes an appreciable fall in temperature, so that the efficiency of alternating arc lamps with ordinary carbons in general falls below that obtained with direct current. It also appears that the form of wave of the alternating current supply affects the efficiency. The use of a choking coil in preference to a series resistance is stated to be beneficial, in some cases an economy of 36 per cent. being secured by this means.[1]

"Flame" and Impregnated Carbons.—Many substantial improvements have been made in the carbon arc lamp. The tendency to flicker which is sometimes experienced arises partly through impurities and want of uniformity in the carbons and partly through defects in the regulating mechanism, and in the best forms of lamps both these weaknesses have been greatly mitigated. Much experimental work has also been devoted to improving the luminous efficiency of the carbons by impregnating them with suitable solutions, or by mixing certain ingredients with the carbon in the form of fine power. Prof. S. P. Thompson has mentioned that so long ago as 1878 he was making researches in this direction, and one of the authors approached him on the subject about 1896. Ordinary carbons were sliced into two halves. One half was treated with impregnating solutions, the two portions were bound together again, and an arc was struck. It was then evident that the part of the crater resting on the impregnated carbon was much

[1] *Illum. Eng.*, London, vol. iv., 1911, p. 270.

the brighter.[1] However, at that date no manufacturer in this country could be induced to take the matter up.

To-day mineralised and treated carbons are a feature in many of the most efficient lamps, but perhaps the most radical departure has been the introduction of a core composed of special chemical materials in the so-called flame carbons. In the flame arc lamp a radical change was made by abandoning to some extent the principle of utilising an incandescent solid. Whereas in the older form of arc practically all the light came from the incandescent carbon on the crater, in the flame arc lamp it is derived mainly from a bridge of highly luminous vapour, sometimes three-quarters of an inch long or more. In a later chapter something will be said regarding the distinction between the effects of "luminescence" (*i.e.* the production of light by the free vibrations of gases and vapours) and the incandescence characteristic of the crater of the carbon arc. For the moment it may be said that the chief feature of such radiation is the production of light-giving line-spectra, and of a colour somewhat removed from what is generally considered "white light." In the case of most flame arcs a strong yellow or orange tint is secured by the presence of several vivid lines in this region of the spectrum. This in part explains the high luminous efficiency of such sources.

The first experiments with flame carbons were unsuccessful, mainly because it was not recognised that the physical conditions were entirely different from those met with in the carbon arc, and that the regulating mechanism must be designed accordingly. In addition to this, it was found that when vertical carbons were employed a non-conducting slag tended to form on the electrodes and interrupt the arc, and that a slight lack of uniformity in the chemical core greatly prejudiced the evenness of burning. The fumes produced from the arc were also troublesome, and in some cases were allowed to enter the chamber containing the regulating mechanism, causing corrosion.

Nowadays these difficulties are successfully avoided. It is possible to design carbons which yield a highly luminous flame yet can still be burned in a vertical position. But it has become usual to employ inclined carbons in the manner shown in fig. 37, a method which has several distinct advantages.

In the first place, it will be seen that there is now no obstacle to the downward direction of the light, and the shadow caused

[1] *Jour. of the Inst. of Elec. Engrs.*, vol. xxvii., No. 133, pp. 184-185, 1898.

by the negative carbon therefore disappears. An important factor in the action of most flame arcs is also the introduction of an electro-magnet somewhat above the arc, which serves the purpose of repelling the bridge of luminous conducting vapour and causing it to assume a fan-like shape.

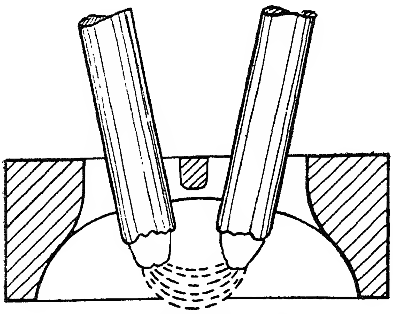


FIG. 37.—Inclined flame carbon in economiser.

In the second place, the tendency to the formation of a permanent deposit of slag is considerably lessened.

The Bremer flame arc lamp, which appeared about the commencement of the present century, produced quite a sensation on account of the unusual colour and distribution of light, the high candle-power, and the original nature of its design. It has been followed by many other forms of flame arcs also using

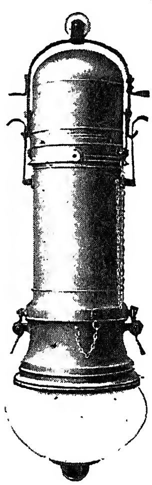


FIG. 38.—A general view of Excello flame arc lamp.

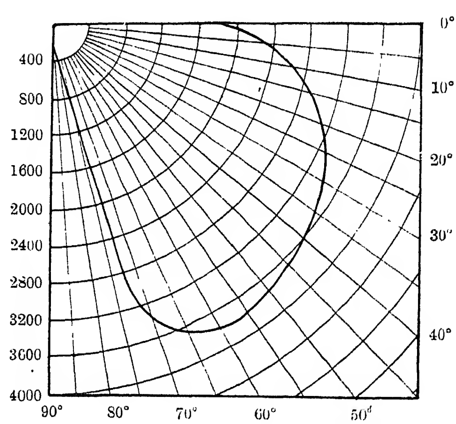


FIG. 38A.—Corresponding polar curve of light distribution.

(The candle-power of a 10-amp. arc is stated by the manufacturers to be as follows: Mean hemisph. c.p. = 1736; mean sph. c.p. = 3100.)

inclined carbons. In fig. 38 we give a general view of a typical Excello arc lamp and a curve showing the distribution of light. It will be observed that the use of inclined carbons favours a strong downward component. It is, however, sometimes desir-

able to modify this curve for street lighting by using a prismatic globe, intensifying the light at an angle slightly below the horizontal (see Chapter VIII.).

The luminous efficiency of such lamps represents a marked advance beyond the best results attainable from ordinary carbons, a consumption of less than 0·3 watt per mean spherical c.p., or 0·15 watt per mean hemispherical c.p., being claimed for the very latest types.

The tendency to deposition of fumes on the globe, with a resultant obscuration of the light, has also been substantially overcome. For example, the Union Electric Co. has embodied

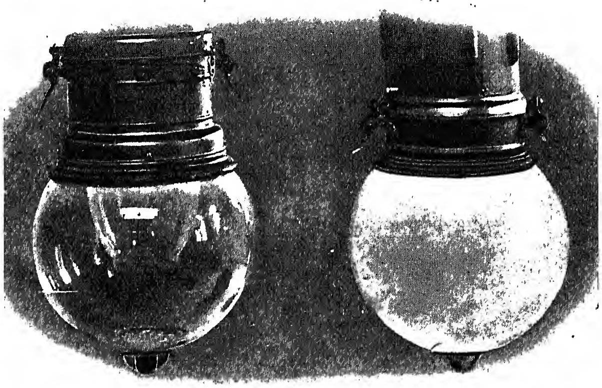


Fig. 39.—Showing appearance of Excello arc lamp after burning 10 hours, with and without deposit-free cover.

in the Excello lamp a form of clear inner globe which conducts away the fumes and enables them to condense harmlessly outside the inconvenient area. If a lamp unprovided with this inner globe is allowed to burn for 100 hours without the globe being cleaned the obscuration becomes very evident. But it is claimed that a lamp equipped with the ventilating inner globe is not appreciably affected. Fig. 39 provides an interesting comparison of two such lamps.

Blondel has remarked that in the case of lamps using inclined electrodes a central chemical core of chemical material is almost invariably used. But in the case of lamps using the upright carbons a different method is usually adopted. The highly efficient carbons devised by Blondel[1] himself are stated to con-

[1] I. Ladoff, "The Blondel System of Arc Lighting," *Illum. Eng.*, New York, vol. ii., 1907–8, pp. 18, 128, 200.

sist in an outer ring of pure carbon surrounding one or more concentric rings of mineralised material inside. Such carbons have been utilised with excellent results for street lighting in Berlin and elsewhere, and the same principle is employed in the Crompton lamps introduced in this country. It is claimed that the rapid consumption characteristic of flame carbons is considerably less with electrodes of this description, and the specific consumption of the lamp appears to be exceedingly low—about 0·2 watt per mean sph. c.p. A feature of the "Alba" carbons used in the lamps employed in Berlin is the brilliant white light.

Mr Maurice Solomon[1] has recently given the following figures for several well-known forms of flame arc lamps:—

Type of Lamp.	Watts.	Watts per Mean Sph. c.p.	Watts per Mean Hemisph. c.p.
Excello	450	0·276	0·145
Angold	435	0·313	0·159
Jandus	357	0·458	0·374
Crompton-Blondel . . .	396	0·178	0·095

It may be observed that the very high luminous efficiency yielded by the flame carbons is offset by one difficulty—the rapid wasting away of the carbons. In the case of the lamps first introduced the life of the carbons frequently did not exceed about 6 to 8 hours. Even this result was only secured by using exceedingly long carbons, and the great over-all length of many lamps is still a drawback. But improvements are being made. In the case of the Excello lamps, for example, the life of a single pair of carbons is given as about 10 to 18 hours, according to type; while by using two pairs burning consecutively in the same lamp it is stated to be possible to secure a life of 34 (or in a very still atmosphere even 42) hours without recarboning.

An extension of this principle was introduced in the Oriflamme magazine lamp, in which a series of carbons are brought into use successively as soon as each pair is consumed. In the Gilbert lamp recourse was had to the method of burning a number of carbons side by side simultaneously. Yet another form of magazine lamp, the Angold, uses nine pairs of carbons in succession, a burning life of 80 hours being stated to be obtained thereby.

[1] Paper read before the Inst. of Elec. Engrs (local section), *Electrician*, May 3, 17, 1912.

Enclosed Flame Arcs.—Another possible method of overcoming the objection of the short life of flame carbons is to enclose the arc. In the case of the ordinary carbon arc this device has proved its utility, and in the United States, where

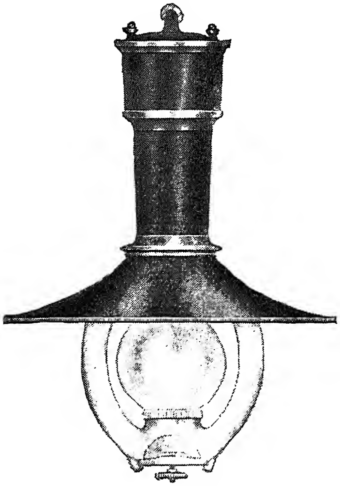


FIG. 40.—General view of Jandus enclosed flame arc lamp.

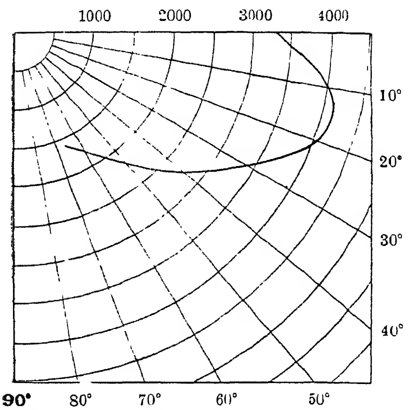


FIG. 40A.—Polar curve of light distribution from Jandus enclosed flame arc lamp.

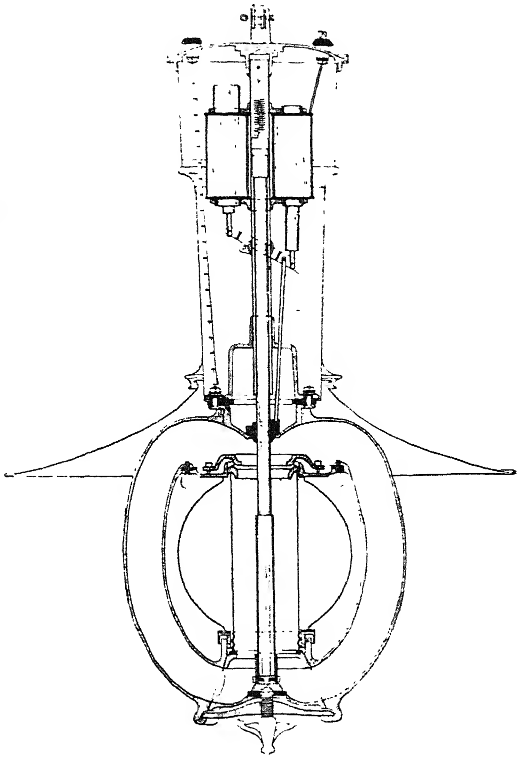


FIG. 40B.—Sectional view of Jandus enclosed flame arc, showing details of construction.

labour is comparatively dear, this form of lamp was almost exclusively employed at one time. Seeing that such a very high efficiency had been secured by using flame carbons, it appeared well worth to attempt to apply the same method in order to secure longer burning hours. There were, however,

certain obvious difficulties, notably the tendency for the fumes to condense in the confined space and rapidly obscure the globe. Special provision was therefore necessary to cause them to deposit elsewhere.

In the Jandus Regenerative arc, a somewhat original method was adopted. The vertical carbons are enclosed in a clear glass cylinder surrounded by a second (usually opaline) globe. The space between these two vessels acts as a heat-insulating jacket and causes the air inside the cylinder to be maintained at a very high temperature, such that no deposition of solid material occurs. At the sides of the lamp are two symmetrically placed ring-like receptacles in communication with the central glass cylinder. The heated gases ascend and stream into these metal tubes, where the solid suspended matter is deposited, and are then sucked in again at the base of the chimney, and the cycle of operations continues. It will be seen that fresh atmospheric air cannot enter the vessel containing arc, so that the oxidation is reduced to a minimum, and it is stated that the circulation of the hot vapours, already saturated with chemical products, also serves to diminish the wasting of the carbons. Lamps taking 3, 5, and 8 ampères respectively are available. It is claimed that they will burn for 70 to 120 hours, according to the current, without recarboning, and that a specific consumption of only 0·2 watt per mean hemisph. c.p. is obtained.

Prof. S. A. Rumi[1] and Sig. A. Pugliese[2] have described a new form of carbon arc lamp which is practically enclosed and uses vertical impregnated carbons (*e.g.* of the "T.B." variety). This is stated to burn for 80 hours without requiring trimming, and the method of avoiding deposition of fumes is of interest. The general appearance of the lamp is shown in fig. 41. The upper part of the globe A is lightly opalescent, the lower part B is pear-shaped and composed of milky glass. The globe is pressed tightly against a metal plate surmounting the carbon holder. The temperature of the upper portion of the globe is very high, and no condensation occurs in this region. The heavier products of combustion sink gradually into the cooler portion B, and therefore their deposition only slightly affects the light from the lamp. A certain portion of the lighter products pass slowly into the cool ringed space C and some emerge eventually through the holes at A. The fumes cannot find their way into the en-

[1] *Illum. Eng.*, London, vol. iv., 1911, p. 271.

[2] *Atti della Assoc. Elettrotecnica Italiana*, March 1911, p. 151.

closure containing the regulating mechanism; lamps taking respectively 8, 10, and 12 ampères are available, and the specific consumption is given as about 0·34 watt per mean hemisph. c.p. Several forms of enclosed flame arc lamps (*e.g.* the Abbey type) were exhibited at the Electrical Exhibition in London in 1911, but not much has been published about them as yet.

Arc Lamps using Metals and Metallic Oxides.—A considerable amount of work has been done on the use of metals

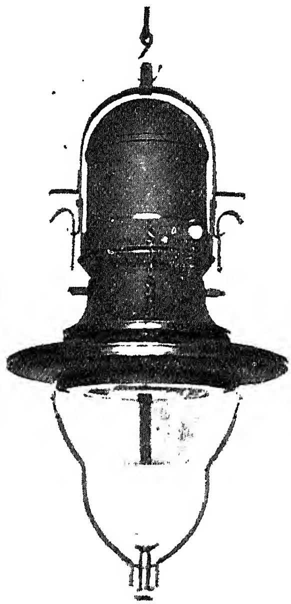


FIG. 41.—Carbone enclosed flame arc.

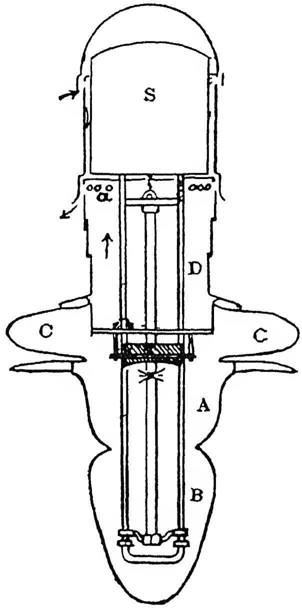


FIG. 41A.—Diagram of Carbone flame arc lamp.

and their oxides for arc lamp electrodes. Readers may be referred to an instructive series of experiments on mixtures of aluminium, titanium, chromium, and other oxides carried out by Dr B. Monasch,[1] who also gives a list of references to the researches of Blondel, Steinmetz, Whitney, and others. Useful compilations have also been made by I. Ladoff.[2]

It would seem that the only commercially practicable form of lamp of this kind is the magnetite or so-called "luminous" arc lamps so widely used in the United States. The characteristic

[1] *Illum. Eng.*, London, vol. iii., 1910, pp. 253, 394, 427.
[2] *Illum. Eng.*, New York, vol. i., 1906–7, pp. 521, 612.

of this form of lamp is that the negative electrode consists in a mixture of the oxides of iron, chromium, and titanium, enclosed within a thin iron shell. The constitution of the positive electrode is immaterial, and usually consists in a slab of some good conductor such as copper. The physical problems met with in connection with arcs struck between metals and their conditions of stability have been very completely worked out by Steinmetz. It appears that the temperature of the electrode has very little bearing on the efficiency, and it is this circumstance that is mainly responsible for the very slow rate at which the electrode burns away. The blast of vapour from the negative electrode takes the form of a brilliant white vertical column about 1 inch long, and the specific consumption is stated to be about 0·6 to 0·8 watt per mean sph. c.p. It is necessary to make a compromise between high efficiency and life of electrodes, which can be done by varying the percentage of the constituents if the electrodes are mixed. The ordinary lamp consumes about 4 ampères and 70 volts, and one negative electrode is stated to last for about 150 to 175 hours. The positive only wastes away very slowly.

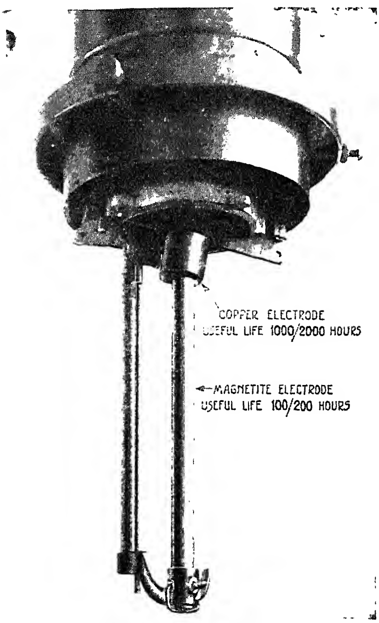


Fig. 42.—General view of magnetite arc.

By the courtesy of the British Thomson-Houston Co., we reproduce in fig. 42 a view of this lamp, showing the general appearance and nature of the electrodes.

The long white arc between vertical electrodes is considered to be exceptionally serviceable for street lighting. The action of the lamp renders it essential to employ direct current, and when only alternating supply is available an electrolytic rectifier is commonly used. The long interval for which the lamp will burn without renewal of the electrodes is a great asset in the United States, where labour is dear, and the lamp appears to have replaced the ordinary enclosed carbon arc to a very great

extent. A difficulty that has sometimes been experienced with these lamps is a tendency to flicker and "dim spells." According to Litle this can be explained by following out the analogy with an ordinary combustible flame. The magnetite flame tends to "soot" in the same way, and consists in several distinct more or less luminous zones. In general the brightest part of the flame is situated at the negative end, and he therefore recommends making the negative electrode the upper one, and providing a suitable down draught to steady the flame. By this means the intensity of the light in a downward direction is improved and the inclination of the flame to form an envelope of soot is lessened. Litle also mentions that there are apparently some materials which act towards titanium oxide in the same way as cerium oxide towards thorium oxide in the mantle. They apparently cause the titanium oxide to give more light without being light-producers themselves. It is hoped by this means to improve still further the luminous efficiency.[1]

Improved Enclosed Arcs and "Miniature" Arcs.—Another direction in which progress has been made is in the design of small enclosed carbon arcs of improved efficiency ("Sparbogen-lampen"). This is due partly to suitable selections of the carbons, and partly to the recognition that better results are obtained by allowing a small access of air, and not aiming at an extremely long extension of the burning hours. German lamps of this kind consume about 3 to 7 amperes and give about 0·5 to 0·75 watt per mean hemisph. c.p., according to type. With the lower of these consumptions the period of burning would probably be from 25 to 40 hours.

Rosemeyer has described the Regina, Reginula, and Helia lamps of this class. With the former a consumption of only 0·8 watt per mean hemisph. c.p. and 200 burning hours are said to be obtained; in the case of the Helia lamp the specific consumption is reduced to only 0·5 watt per c.p. and the corresponding life of the carbons to about 40 to 50 hours.[2]

A development of this class which seemed at one time likely to meet with great success was the design of the so-called "miniature" lamps, taking only 3 or even 2 amperes. These lamps were issued under various fanciful names (the Midget, Miniature, Lilliput, etc.). It would seem, however, that the coming of the metallic-filament lamps, with their facilities in the

[1] *Electrical Journal*, Feb. 1912, p. 157.

[2] *Illum. Eng.*, London, vol. i., 1908, p. 991.

direction of increased candle-power, has rendered them superfluous. Indeed, some authorities contend that the high candle-power tungsten lamps, consuming only ½ watt per candle, are destined to take the place of all but the most powerful and efficient flame arcs. At the present moment the tendency in electric street lighting is to use flame arcs in the important thoroughfares and tungsten lamps for side streets.

It remains to mention briefly several other points in the design of arc lamps that are receiving attention. Efforts have been made to simplify the mechanisms and even to rely on a gravity feed. Among lamps of this class may be mentioned the Beck and Conta types.[1] Another matter that demands attention is the loss in resistance in series with arc lamps. In practice this almost invariably exceeds considerably that which theoretical consideration would suggest as desirable to ensure the stability of the arc. For example, the consumer who only requires a single open arc lamp on a supply of 200 or even 100 volts might have to waste the greater part of the energy consumed. There is therefore room for ingenuity in the grouping of arc lamps on high-voltage circuits. This point has been alluded to by W. Hechler in a very serviceable series of articles reviewing the arc-lamp situation.[2] He points out the desirability of increasing the p.d. allotted to the flame arc. A step in this direction was taken in the Carbone high-voltage lamp, designed to take 80 volts across the arc. Again, in the Jandus enclosed flame arc lamp the regulation of the strike of the arc enables the lamps to be run 2, 3, or 4 in series on 200 volts, the p.d. across the arc being adjustable between 50 and about 75 volts. In some cases, again, two arcs may be run in series within the same globe. Yet another device is exemplified by the Union Electric Co.'s "Economy" system, specially applicable to shop lighting. Here a combination of flame and enclosed lamps is utilised so that they can be run in series-parallel for the indoor and outdoor lighting. The supply voltage can thus be utilised with a minimum loss in the external resistance.

In the United States it is very customary in the case of public lighting for the magnetite arcs to be run in series on a constant current system, which reduces the loss in series resistance to a minimum. A very interesting installation of this kind was

[1] *Illum. Eng.*, London, vol. iii., 1910, p. 19.

[2] *Elektrot. Zeitschr.*, 21st March 1912; see also 1909, pp. 341, 703, 1055; 1910, p. 963.

recently carried out at the Turin electrical exhibition, 240 "Conta" lamps being run from 6300 volts.[1] When the series system is employed it is of course necessary to provide the lamps with automatic cut-outs, so that in the event of one lamp going out the whole circuit will not be interrupted.

Arc Lamps with Horizontal Carbons, Projection Arcs, etc.—A word or two may be said on several new forms of lamps using special arrangements of carbons. One of the most interesting of these is the Timar-Dreger lamp recently described by Wedding, which utilises two pairs of horizontal flame carbons.[2] An electro-magnet is used to blow the arc downwards. The two pairs of carbons are arranged in series so as to run direct

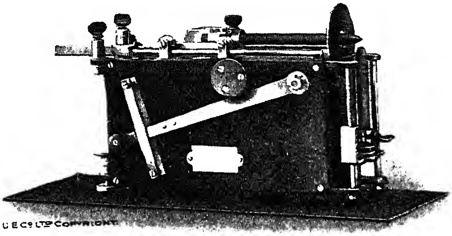


FIG. 43.—Union projection arc lamp for lantern work. (Carbons at right angles.)

off 110 volts. The specific consumption appears to be about 0·25 watt per mean hemisph. c.p. (H.K.), and the life of the carbons is about 8 to 10 hours. The arrangement of the carbons is favourable to good downward distribution of light, and the lamp appears to be of a compact form, very convenient for mounting on the ceiling in low rooms. If it is desired to project the light sideways a single pair of carbons may be used.

A form of projection lamp has been introduced by the Union Electric Co. in which the carbons are mounted at right angles, the horizontal carbon being the positive. This, again, enables the light to fall direct on the condenser without obstruction from the negative carbon, and the gain in light is stated to be considerable. Another feature of this lamp is the compact automatic feed, which enables the operator to switch the lamp on and off from a distance if so desired.

One other comparative novelty is the three-phase lamp, of

[1] *Illum. Eng.*, London, vol. iv., 1911, p. 673.
[2] *Elektrot. Zeitschr.*, 1910, p. 34.

which several designs have been made. In one of the latest of these, three carbons attached to the respective mains and converging on a fourth neutral electrode are used.[1] More recently still, Wedding has described a lamp of this kind using three converging inclined flame carbons meeting beneath an economiser in the customary way, and giving a specific consumption of 0·088 to 0·21 watt per mean hemisph. c.p., according to the current and carbons used.[2]

In concluding this section it may be of interest to summarise briefly the qualities of some of the chief forms of arc lamps in tabular form. The data for this table are derived mainly from the published figures of Blondel, Barrows, and Monasch, supplemented by more recent data kindly placed at our disposal by the manufacturers. Such figures can only be given approximately. In the first place, exact photometry of arc lamps presents certain well-known difficulties. Again, an arc lamp is a more complicated apparatus than an incandescent lamp, and comparatively small modifications in its adjustment sometimes produce a very appreciable effect on the light. It may be said, however, that the authorities named are in substantial agreement, and the authors' experience leads them to regard the following data as generally correct. The results are given in terms of mean hemispherical candle-power, this being now regarded as the most convenient method of stating the light from a practical standpoint.

The figures for the power consumed apply to the arc itself, and are exclusive of that spent in external resistance.

Type of Lamp.	P.D. across Arc.	Current.	Watts.	Mean hemisph. c.p. (lower).	Watts per hemisph. c.p.	Consumption of electrodes (mm. per hour).	Approx. Burning Hours.
	volts.	amps.					
Carbon (open)	40	9	360	700	0·5	14–16	12–20
Carbon (enclosed)	70	6–7	430	320	1·4	1·5–2	150–200
Flame arc (open)	45	9	405	2800	0·15	35–45	8–20
Flame arc (enclosed)	70	8	560	2800	0·2	3–6	70–120
Blondel arc	50	5	250	1880	0·13	16–20	12–20
Magnetite arc	90	3·5	315	400	0·8	1–2	50–200
Miniature arcs	80	3	240	270	0·9	4–5	40–60
Three-phase flame arc	110	4·7	650–1250	3050–7960	0·088–0·214	15·5–34	...

[1] A. Righi, *Lum. Electrique*, 9th April 1910.
[2] *Elektrot. Zeitschr.*, 6th June 1912.

VAPOUR LAMPS.

We now come to an entirely distinct class of electrical lamps—those using luminescent vapours. The illuminants hitherto described have mainly utilised incandescent solid materials. The flame arc, it is true, utilises luminous vapours to some extent, but the gaseous luminescence from such lamps is mixed with incandescence from the luminous ends of the electrodes. The lamps we are about to describe owe their light solely to luminous materials in the state of gas or vapour.

At this point it may be well to make a short digression in order to explain the distinction between these two methods of producing light. In the case of a glowing solid (incandescence) the ions or vibrating particles are so closely packed together that under the influence of heat they vibrate in a confused manner, and cannot follow their natural period of oscillation. Instead of this they appear to vibrate *en masse*, so that a confused series of ethereal oscillations, some of them luminous but others not, is produced. Under these circumstances we find that all the colours are present, and we obtain a continuous spectrum. On the other hand, it requires a considerable temperature before the percentage of energy emitted in a visible form becomes at all appreciable.

In the case of a luminous gas matters are different. The attenuated state of the material apparently permits the ions to follow their natural periods of vibration. Consequently, we find that there are gaps in the spectrum. Certain rays are strongly produced, but others may be entirely missing, and the colour of objects illuminated by such a source may accordingly be distorted. On the other hand, the fact that only certain luminous rays are produced, without the vast series of wasteful invisible vibrations characteristic of incandescence, is favourable to a high luminous efficiency.

At present there are two distinct kinds of lamps based on this principle, (*a*) those using metallic vapours and (*b*) those using permanent gases. The magnetite arc might perhaps be regarded as coming within this first class, but has been conveniently treated among the arc lamps. The only other practical example of the use of metallic vapours pure and simple is the mercury lamp.

The Mercury-Vapour Lamp.—Some of the earliest experiments in this direction appear to have been made by Way in

England and Rapieff in Russia, and more recently by Bastian (also in England). The lamp was brought to a more practical stage by Dr Arons in Germany, who seems to have been among the first to enclose the mercury vapour entirely; and Cooper Hewitt in the United States, working on similar lines, introduced the tube lamp in a commercial form. Such lamps are now well known. They consist in a long exhausted tube with an electrode at each end, and containing a small quantity of mercury. When the lamp is alight, the entire tube is filled with luminous mercury vapour. But special means are necessary to start the lamp. The most trustworthy method of doing so is probably the simple tipping arrangement. The tube is inclined, so that the mercury runs down to one end and makes the contact. When the tube is restored to a horizontal position the mercury runs back into the vessel at its extremity, starting a long arc as it does so. Sometimes the "tipping" is done by hand, but when the lamps are out of reach it can conveniently be done automatically on switching on the current by means of an electro-magnetic solenoid. Other methods have been tried. For example, a high momentary electrical discharge through the tube has the effect of rendering its contents momentarily conducting, and so enabling the current to flow and the lamp to start; or we may use a small subsidiary electrode, where a small arc can be started, whence electrons rapidly find their way throughout the entire tube; a small heating coil above the mercury, which has the same effect; a floating contact actuated by a solenoid outside the tube, etc Most of these methods have proved to be too dependent on temperature, or too easily affected by slight imperfections in the changes in the degree of exhaustion in the tube, to be really practicable.[1]

The physical problems involved in the mercury lamp are of a complicated kind, and readers interested should refer to papers by Steinmetz,[2] v. Recklinghausen,[3] and Weintraub,[4] and others.

The actual length of the tube in a 50-volt lamp is about 50 cms., the current consumed being 3·5 amperes, and the mean sph. c.p. is given as 350. Two such lamps are commonly run side by side in series for 100 volts. The specific consumption is frequently given as being about 0·5 watt per

[1] See Kruh, *Elektrotechnik und Maschinenbau*, 23rd July 1911.

[2] *Trans. Int. Electr. Congress of St Louis*, 1904, vol. ii. p. 710.

[3] *Elektrot. Zeitschr.*, 1904, p. 23; 1902, p. 492.

[4] *Electrical World*, vol. xlv., 1905, p. 887.

candle; but it must be remembered that the extensive area of the source, and its peculiar colour, both render accurate photometry no easy matter. The ordinary lamp is not suitable for use on an alternating current, and in use it is essential to avoid charging its polarity. Like the magnetite arc, it can be used on an alternating p.d. by using a rectifier. Recently, however, F. Girard[1] has described a form of lamp intended for use on an alternating p.d.

The chief limitation to the use of the mercury lamp is imposed by its peculiar colour. Seen through the spectroscope the light appears to be concentrated in three very restricted regions in the yellow, green, and blue-violet. The effect of the gaps in some regions of the spectrum, and particularly the complete absence of red, is that the appearance of coloured objects seen by the light of the lamp is much distorted. For example, a person's face looks green and the lips purple. Numerous attempts have therefore been made to supply the missing rays. Some investigators have tried to introduce certain gases in the tube, or to mix appropriate metals with the mercury, with the idea of adding vivid red lines to the spectrum. Nitrogen, argon, and helium among gases, and amalgams of lithium, bismuth, lead, etc., have been tried, but in every case the result was apparently unsatisfactory.

The failure of these attempts led to the recognition that any effort to improve the colour should be made by means *outside the tube.* The most obvious device was to combine the lamp with others rich in the missing rays. Such combinations have been studied by Ives,[2] who found that tungsten lamps and incandescent mantles were both useful as a means of producing an apparent white light. According to this authority the specific consumption of the requisite combinations with tungsten or carbon-filament lamps would be respectively 0·8 and 1·4 watts per candle, assuming the mercury lamp to give about 0·5 watt per c.p. alone. Combinations of lamps are apt to be cumbrous and inconvenient, but a neat development of the method has recently been brought out by the Cooper Hewitt Co., and was described by J. Pole.[3] The arrangement will be understood from fig. 44A. The mercury tube is in the form of a ring, and a tungsten incandescent lamp is mounted at the centre. The

[1] *Electrot. Zeitschr.*, 4th July 1912.
[2] *Electrical World*, 23rd Sept. 1909.
[3] *Elektrot. Zeitschr.*, 9th May 1912.

whole is mounted in a diffusing glass hemispherical bowl, which serves to "mix" the light from the two sources, so that the lamp has the appearance shown in fig. 44. The 110-volt lamp consumes 2 amperes, gives a mean lower hemisph. c.p. of about 300 (with the diffusing glass bowl), and a specific consumption therefore of about 0·75 watt per c.p.

An entirely different method of attacking the problem of colour improvement has been devised by Dr Cooper Hewitt, namely, the use of a fluorescent reflector. It has long been known that certain materials have the power of fluorescing under the action of light, and of transforming the radiant energy

FIG. 44.—New form of combined tungsten and mercury vapour "orthochromatic" lamp.

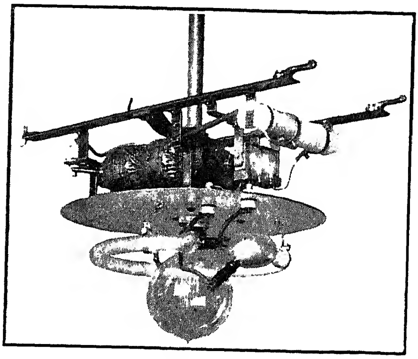


FIG. 44A.—General view of "orthochromatic" combined tungsten and mercury-vapour lamp equipped with outer diffusing glass bowl.

falling upon them into light of a different colour while doing so. Rhodamine and similar dyes fluoresce a red or rather pink colour, and it has been ascertained that the ultra-violet rays are particularly active in giving rise to this transformation. A form of reflector has now been developed which fluoresces pink in the light of the mercury lamp,[1] converting some of the excess of blue and green light and a little of the yellow into red. The reflector is mounted over the tube in the manner shown in fig. 45. The resultant light approaches considerably closer to white than that of the ordinary mercury lamp, and, when studied through the spectroscope, is seen to contain a well-marked band in the red. The difference in this respect is likewise brought out by the appearance of red objects. Under the light of ordinary mercury tube they appear almost black, but by the

[1] *Illum. Eng.*, London, vol. iv., 1911, p. 628.

aid of the fluorescent reflector are made to assume much more nearly their natural colour.

The Quartz Tube Mercury Lamp.—A remarkable development in mercury-vapour lamps has been brought about by the use of tubes of quartz, and an interesting account of the Küch lamp, utilising a tube of this kind, was presented by Dr Bussmann in 1907.[1] Such lamps are now manufactured and sold under different names by several companies, such as the Silica and Quartzite lamps, etc.

Quartz tube lamps were manufactured some years ago by Dr Heraeus of Hanover, mainly with the object of securing a

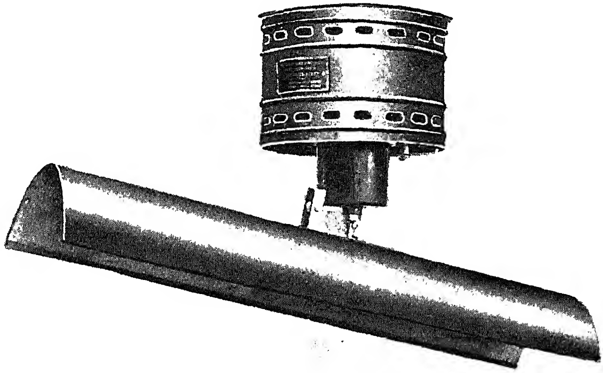


FIG. 45.—Cooper Hewitt lamp with fluorescent reflector.

source powerful in ultra-violet light. But it is only recently they have been utilised for ordinary purposes of illumination. Previous to the introduction of such quartz-glass tubes it was believed that the limit of possible efficiency for mercury lamps was fairly accurately known. Dr Cooper Hewitt had shown that there was a certain pressure within the tube for which the specific consumption was a minimum. Increasing the power given to the tube, and raising the temperature and internal pressure as far as it was safe to go, apparently had the effect of lowering the luminous efficiency. But when, by the use of quartz tubes, it was found possible to increase the temperature substantially above this limit, it was found that the specific consumption began to fall again, and that ultimately a value as low as 0·27 watt per Hefner (mean spherical) could be reached. The initial rise in specific consumption, followed by the pro-

[1] *Elektrot. Zeitschr.*, vol. xxviii., 1907, p. 932.

gressive fall with increasing power given to the lamp, is shown in fig. 46.

In figs. 47 and 47A we produce, by the courtesy of the Westinghouse-Cooper Hewitt Co., a view of the Silica lamp and the accompanying polar curve of light distribution. The 250-volt lamp is stated to consume 3·5 amperes and to give a mean hemisph. c.p. of 3000, the maximum value (4500) being attained at about 65 to 70 degrees. The small over-all length of the lamps appears to be a distinct advantage. The quartz tube for a 110-volt lamp may be as little as 8 cms. long and 1½ cms. in diameter. It can be renewed separately, and is stated to last over 1000 hours before requiring renovation. The quartz tube

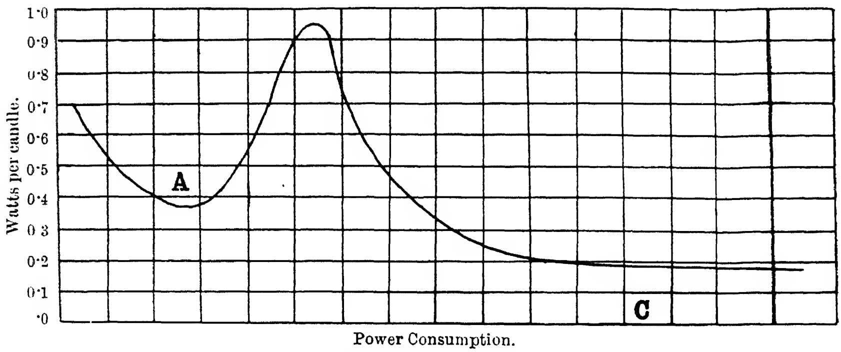


FIG. 46.—Showing the improvement in efficiency of the quartz tube as the power given to the lamp is increased.

The watts per candle are a minimum at A, but by increasing the temperature another lower minimum at C is eventually reached.

is, of course, one of the most considerable items in the total cost of the lamp.

The colour of the light from the quartz lamps, apparently on account of the higher temperature, is somewhat less bizarre than that of the tube lamps. The blue and green elements are less accentuated, and there is even a small amount of energy in the red. Perhaps the most remarkable feature is the transparency of the quartz tube to ultra-violet light. In the long glass tubes of the Cooper Hewitt lamps the glass absorbs by far the greater part of these rays and converts them into heat. But their presence in the quartz lamp has led to its being applied for certain special purposes—such as the destruction of bacteria, the sterilisation of water, etc. In Chapter VI. more will be said on the subject of these ultra-violet rays. It may be said that, when present in excess they appear to exert a powerful and

sometimes prejudicial action on the skin and the eyes. When the quartz tube is used, unscreened, for bacteriological researches, etc., care should therefore be taken to protect the eyes with suitable glasses. When the lamp is supplied for ordinary purposes of illumination it is commonly surrounded with an opalescent glass globe, which is regarded as a protection against any possibly injurious effect of these rays.

The Moore Vapour Tube Light.—The other line of development in vapour lamps started from the utilisation of luminescent gases. It has, of course, long been known that gases become luminous when subjected to an electrical discharge in

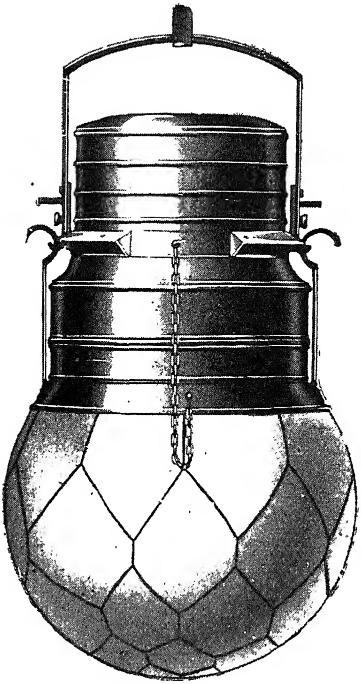


FIG. 47.—A general view of Silica quartz tube mercury-vapour lamp.

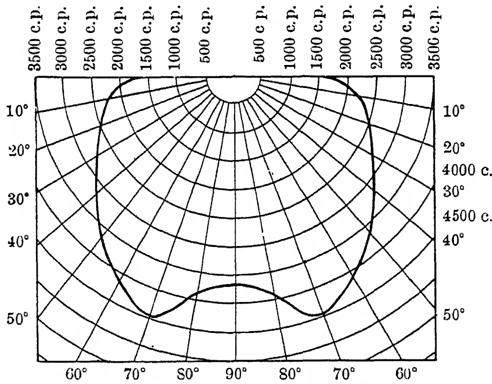


FIG. 47A.—Polar curve of light distribution from Silica lamp.

a highly rarefied condition. The ordinary "vacuum" or Geissler tube, a familiar feature in popular lectures, is an example of the principle. The brightness of the light cast by such tubes is, under favourable conditions, quite considerable, and to Tesla and others the idea had early occurred that they might be made the basis of an efficient commercial illuminant. Naturally, a comparatively large area of tube would be necessary in order to give enough light.

But it was soon found that the conditions within the tube did not remain constant, chiefly owing to the absorption of gas by the electrodes. Now, the light from such lamps is very

sensitive to small changes in the internal pressure, and means had therefore to be taken to ensure the nature and conditions of the gaseous contents being kept constant. It was at this point that the ingenuity of an American, Mr Macfarlane Moore, afforded the solution.[1] In the Moore system of lighting the essential feature is the introduction of a special valve which automatically admits gas into the tube as the supply becomes exhausted. In order to make the valve automatic it is controlled by an electro-magnet which raises or allows to fall a plunger, according as the current supplied to the tube increases or diminishes. The arrangement is stated to be very sensitive, since quite a small alteration in the gaseous conditions within the tube at once affects the conductivity.

By the aid of this device the Moore tube is stated to continue giving out an undiminished light for thousands of hours, and some installations in the United States have already been in operation for some years. The illuminant thus consists of a tube, probably 30 to 40 feet or more long, which is filled with suitable gases at low pressure and receives current from a high-tension transformer. In the case of the installation carried out at the Savoy Hotel in this country some years ago, a pressure across the secondary of 12,000 volts was utilised. In order to secure such high pressures, a high voltage, and therefore an alternating current supply, is practically essential. This is perhaps one of the reasons why the system has not yet been largely employed in England.

It has, however, been installed to a considerable extent in the United States, and more recently also in France and Germany. The length of tube used will naturally depend upon the dimensions of the room to be lighted. Very frequently the method is adopted of arranging the tube to follow the contour of the ceiling, the outline of the shop window, or even the arc in a church. In other cases (for example, in the lecture theatre at the Breslau technical school) a more complicated pattern is adopted with a view to getting more complete uniformity. The essential features of the lamp—the transformer, junction to tube, and valve—are shown in fig. 48, while fig. 49 is a photograph of an office illuminated in this way.

The following data (which we have converted into English measures) are given for the output of energy necessary to illuminate various rooms :—

[1] *Proc. Am. Inst. of Elec. Eng.*, 1906.

Length of Tubes.	Area Illuminated.	Output of Transformer.
feet.	sq. feet.	kilo-watts.
40–60	300–600	2·00
80–120	800–1200	2.75
130–180	1300–1800	3·50
190–220	1900–2400	4·50

The low intrinsic brilliancy of the light (stated to be about 1 to 2 c.p. per square inch) and the feeling of restfulness thus engendered are good features, and it is also claimed that an

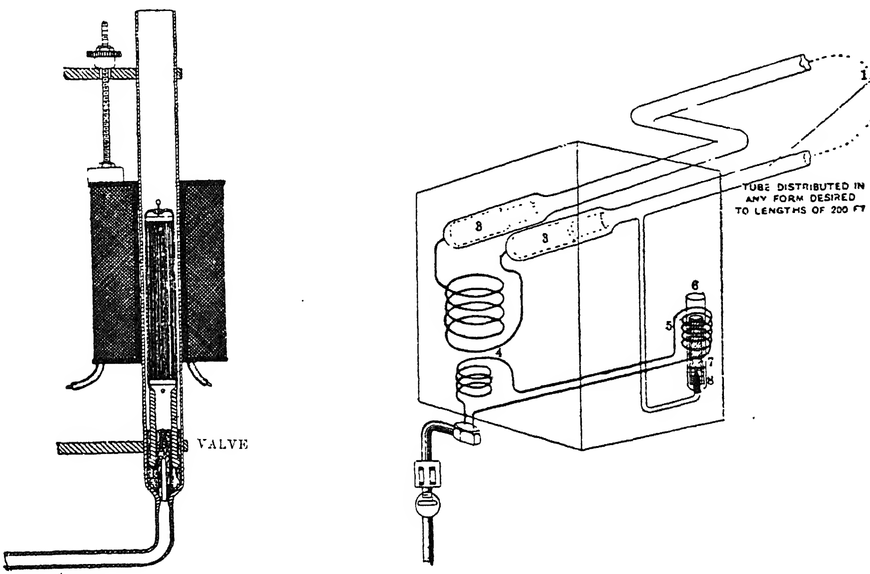


FIG. 48.—Details of Moore light.

installation may be used for years without any attention or maintenance being necessary. It is difficult to give exact numerical figures for the candle-power and specific consumption of the source occupying such a large area. According to Fleming[1] the specific consumption of the Savoy installation might be taken as about 1·8 watts per c.p., while Hyde and Woodwell, in the course of an investigation into a post-office lighted by this means, obtained the figure 2·4 watts per c.p.[2] Wedding appears

[1] *Illum. Eng.*, London, vol. i., Jan. 1908, p. 19.

[2] Paper presented at the Annual Convention of the Illuminating Engineering Society, U.S.A., Sept. 1909.

to confirm this figure approximately, judging the efficiency to be about the same as an installation of tantalum lamps.[1] Perhaps the best criterion as to its efficiency as compared with ordinary electric lighting is to be gained from the study of the illumination produced in actual installations. Monasch,[2] as a result of tests in the installation at the Berlin Palace of Ice, finds that a consumption of about 0·5 watt per lumen (*i.e.* watts per foot-candle per square foot illuminated) is obtained, measurements

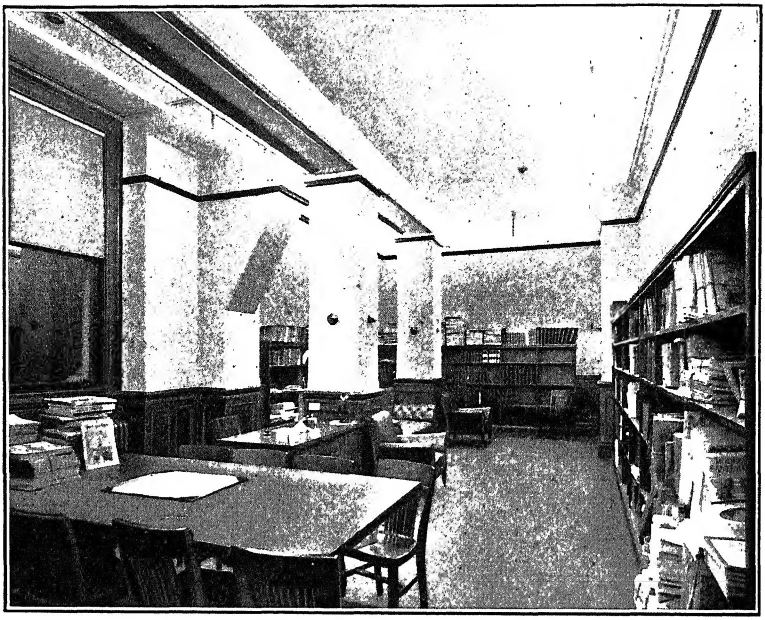


FIG. 49.—Office illuminated by the Moore light.

being taken in a horizontal plane one metre from the floor. Hilpert,[3] in giving particulars of the installation at the Breslau Technische Hochschule, gives roughly the same figure.

The above refers to the most usual form of tube containing nitrogen. The colour of the light is in this case somewhat pinkish. When, on the other hand, carbon dioxide is used, an extremely white light is obtained, which has been asserted to be, from a colour-matching standpoint, extremely close to daylight. Quite small and compact arrangements, comprising only a few

[1] *Elektrot. Zeitschr.*, May 19, 26, 1910.
[2] *Elektrische Beleuchtung*, part ii., 1910, p. 66.
[3] *Elektrot. Zeitschr.*, 2nd Nov. 1911.

feet of tube, have been devised for use over a restricted area, as a "daylight window." The imitation of white light, as usual, occasions a certain loss in efficiency, and the carbon dioxide tube appears to be less efficient in this respect than the nitrogen one. However, for the purpose for which the white light is mainly desired, a certain loss in efficiency will often be tolerated in view of the advantage of being able to carry on accurate colour-matching work by artificial light. As explained in Chapter V., the first installation of this kind in London [1] has just been carried out at a well-known hop merchant's in the City. This is one other instance of the many trades in which accurate colour-matching is needful. According to some recent articles,[2] the possibilities of the Moore light can be considerably extended by introducing a spark gap into the secondary of the transformer, used with the Moore light so as to superimpose an extra high-tension discharge over the ordinary p.d. The nature of the wave form and the colour of the light can be modified in this way, and it is even possible that electrodes (acting like condensers) entirely outside the tube might be utilised. It is hoped that by this means the absorption of gas by the electrodes, and the consequent necessity for the special valve used with the Moore light, might be avoided.

The Neon Tube.—The Moore tube, as remarked above, utilises either nitrogen or carbon dioxide. But more recently a striking development has been introduced by M. G. Claude,[3] namely, a tube illuminant making use of the rare gas neon. Such a lamp certainly presents a most interesting example of the rapidity with which science is now applied to practice. It is only a few years since Sir Wm. Ramsay succeeded in isolating from the atmosphere the rare gases—argon, helium, and neon. Argon may prove of value in the new "half-watt" incandescent lamps. Helium tubes have been developed in the United States by P. G. Nutting, with the idea of securing by this means a standard of light. And by using the gas neon it seems probable that a new and efficient commercial illuminant will be obtained.

In his contribution on this subject M. Claude points out that gases differ very much in their power of emitting light when electrically excited. Nitrogen takes about 1·7 watts per c.p., carbon dioxide about 2, and hydrogen approximately 10 watts per candle. With neon, on the other hand, he has found it

[1] *Illum. Eng.*, London, Oct. 1912, p. 465.

[2] *Zeit. f. Beleuchtungswesen*, 30th May 1913.

[3] *Soc. Int. des Électriciens Bull.*, Nov. 1911, p. 505.

possible to secure a specific consumption of only 0·5 watt per candle. The dimensions of a tube necessary to give a certain candle-power, and consequently the voltage required from the transformer, are therefore considerably less than in the case of the Moore lamp. For example, he states that a tube 6 metres long requires only about 800 volts and gives about 900 c.p. The light produced is, approximately, 200 c.p. per metre, as compared with 50 c.p. per metre for the Moore lamp.

It might, naturally, have been supposed that the fact of the tubes requiring to be filled with such a comparatively rare gas as neon would have been a great disadvantage. M. Claude, however, states that with his extracting apparatus 100 litres of neon can be obtained in a day, and that this would be enough for 1000 tubes, each giving 1000 c.p. Perhaps the most interesting circumstances connected with the lamp is that it appears to be unnecessary to use an automatic valve of any kind to maintain the gaseous conditions in the tube constant. Such a valve is rendered necessary in the case of the Moore tube, largely because the gas tends to be absorbed by the electrodes. Neon has the advantage of being only very slightly absorbed, and by making the electrodes sufficiently large it is said that the tubes will continue to work satisfactorily for more than 1000 hours without any sign of deterioration. The neon spectrum is rich in the red and orange rays, and it has been suggested that the lamp might therefore be very effectively used in contrast to the mercury-vapour lamp for decorative purposes. By varying the self-inductance in series with the tube, the current consumption can be varied within wide limits, and this presents an economical and convenient way of adjusting the light.

During a recent visit to the Continent, one of the writers had the privilege of inspecting one of these lamps at Laboratoire Central d'Électricité. It is certainly an interesting illuminant, and, if the claims made for it are justified by further experience, seems destined to be of considerable service for spectacular lighting.

As regards the cost of electric lighting, the remarks made in connection with gas lighting in Chapter II. should be borne in mind, namely, that conventional tables on this subject have only a limited application in practice, owing to the variety of local circumstances to be considered. Readers may be referred to some exceptionally full data in Mr Maurice Solomon's book on *Electric Lamps* (p. 294).

CHAPTER IV.

OIL, PETROL-AIR GAS, AND ACETYLENE LIGHTING.

Development of the Oil lamp—Effect of Variety of Petroleum, Chimney, Height of Liquid in Reservoir, etc.—Incandescent Oil Lighting—Alcohol and Liquid Gas—Petrol-air Gas Lighting—Advantages of "rich" and "poor" Mixtures—Various Types of Plant and Motive-power—Defects to be avoided—Petrol-air Gas Burners—Opportunities of Petrol-air Gas Lighting—Acetylene, how formed, early difficulties, generating apparatus—Acetylene Burners—Cinematograph Lamps and Incandescent Oxy-acetylene Lighting—Dissolved Acetylene—Special Uses of Acetylene for Emergency Lighting, in Navigation, etc.—Automatic Solar and Flash-light Valves.

In the historical introduction in Chapter I. we traced the gradual development of gas and electric lighting, by which candles and oil lamps have been so largely superseded. Yet there are many occasions when these illuminants cannot conveniently be used, and there have come into being other and newer methods of lighting, such as acetylene and petrol-air gas, which are specially useful in remote country districts where gas and electricity are not available.

Oil Lamps.

We have seen how in past centuries the crusie oil lamps, burning coarse home-made oil, formed the usual method of domestic lighting. It was not until the discovery of petroleum in the United States midway through the nineteenth century that any very notable step forward was made.

The modern petroleum lamp is a great help and by no means to be despised as an illuminant. The fact that as much as 100 c.p. can be obtained by such simple means, and that the lamp itself contains fuel and does not have to be fed from a distance, are distinctly advantageous. Even in England there are, of course, many country houses and roads and small railway stations lighted quite effectually by this means, and it must not be forgotten that in less progressive countries the use of petroleum for lighting is much more general. The ordinary

petroleum lamp, of course, needs a certain amount of care and attention, and it is often unjustifiably blamed for certain defects which are not inherent and can be avoided by suitable design. This question was the subject of discussion at the International Petroleum Congress held at Bucharest in 1907, when papers were presented by M. Aug. Pihan, Herr Proessdorf, and one of the authors. A resolution was moved subsequently asking that the Congress should study and decide upon a type of domestic lamp fulfilling the conditions of the greatest safety and highest efficiency; and this suggestion was formally adopted.

This question of safety is indeed a very vital one to the success of oil lamps, and previous to this Congress many prizes had been offered for a lamp which would satisfy the required conditions, but without one being discovered that was considered worthy of the prize.

It may also be pointed out that the design of any particular lamp must take into account the nature of the petroleum which is intended to be used with it. For instance, a lamp intended for American oil would not serve equally well for use with the Russian variety, nor, probably, would the type of chimney favouring the best conditions of combustion be the same in the two cases. The result of trying to burn a variety of petroleum different from that for which the lamp is designed will probably only lead to the production of incomplete combustion, a smoky flame, and a smell.

Considerable difficulties have been experienced in preparing Roumanian oil in a condition such that it answers as well for illuminating purposes as the American and Russian varieties, but a recent process invented by Dr Edeleanu seems likely to be very useful in this respect. Dr Edeleanu found that the objectionable qualities from a lighting standpoint were caused by the presence of a certain proportion of "closed chain" aromatic unsaturated hydrocarbons, which are not removed by the ordinary processes of purification. By treatment with sulphur dioxide this objectionable ingredient can be removed, and the oil is then fit for purposes of illumination. It is expected that this process will also be of value in connection with the purification of qualities of petroleum found in Galicia, some parts of Russia, W. America, the Dutch Indies, and some parts of the British Dominions, which have hitherto proved unsuitable for lighting.

Another point that is worthy of notice in connection with oil lamps was recently raised by M. Guiselin,[1] who has pointed out that the light of an oil lamp was affected by the quantity of oil in the reservoir. For example, after burning ten hours some lamps containing about half a litre were found to be giving only 70 per cent. of their candle-power when first lighted. This can readily be understood when we recall the influence of the level of oil on the capillary action of the wick. The user would therefore do well to keep the lamps well filled up, and it is scarcely necessary to add that the filling should be done with care owing to the inflammable nature of the oil.

According to some figures given in Mr H. Fowler's well-known paper on railway lighting,[2] it would appear that under the best conditions as much as 800 to 1000 c.p. hours can be obtained per gallon of petroleum. Monasch, however, points out that the figures usually quoted refer to the horizontal instead of the mean spherical candle-power of such lamps, and advocates that comparisons with other systems should be made on the basis of providing a certain illumination over a given area.[3]

Incandescent Oil Lighting.

The great advance secured by using the incandescent mantle with coal-gas naturally suggested the application of the principle of incandescence to liquid fuels. It was recognised that if a liquid illuminant could be vaporised and mixed with air in the correct proportions, it might be utilised to heat an incandescent mantle to even greater brightness than that obtained from ordinary town gas. One of the first attempts to use petroleum in this way was that of Mr Arthur Kitson, which was described in the paper before the Royal Society of Arts in 1903. A paper on "The Illumination of Engineering Workshops," read by Mr J. E. Evered of the United Kingdom Lighting Trust before the Manchester Association of Engineers on 25th January 1913, contains some interesting information on the incandescent oil systems.

The essential elements are the lamp, the oil reservoir, and the tubing. The reservoir may either be connected immediately to the lamp, or may be some distance away and connected by piping. It is filled one-third full of petroleum, and air is then

[1] *Illum. Eng.*, London, vol. i., March 1908.

[2] Institution of Mechanical Engineers, 1906.

[3] *Elektrot. Zeitschr.*, vol. xxxiii., 18th July 1912, p. 738.

pumped in until a pressure of 50 to 75 inches is obtained. When the valve is opened this pressure forces the oil through the piping to the lamp, and it is then admitted to a specially designed vaporising chamber. The vapour passes into the burner and brings the mantle to vivid incandescence. It will be noted that some means of starting this vaporisation is necessary. The initial lighting up of the lamp may be accomplished by igniting spirit, by a gas flame, or by electrical means, and the process should only require a few minutes. The lamp then continues to generate and burn oil vapour automatically. One of the latest types of these lamps is shown in fig. 50.

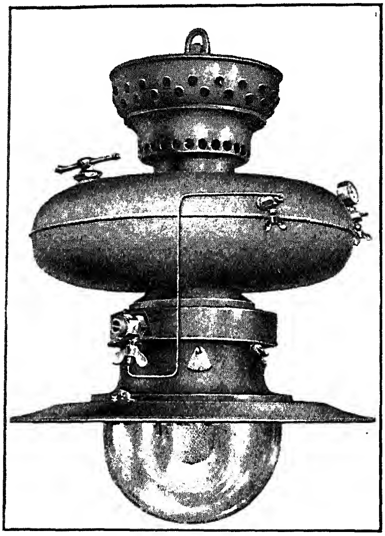


FIG. 50.—Self-contained "Still" incandescent oil lamp (United Kingdom Lighting Trust).

These lamps are stated to give 300 to 1200 c.p., and to burn from 200 to 300 hours without cleaning.

Such lamps can be readily transferred from place to place, and are therefore of special use for emergency work in railway yards, erecting buildings, road excavations, etc. On the other hand, the lights may be supplied from a central reservoir through pipes, and the space occupied is then remarkably small. For example, it is stated that a tank capable of giving 200,000 c.p.-hours only occupies 10 square feet—an area which would have to be considerably exceeded in order to accommodate an electric or gas-lighting plant of similar output.

The latest form of lamp using inverted mantles is stated to burn for 100 to 150 hours without attention, and it is also claimed that with the larger types of lamps as much as 14,000 c.p.-hours can be obtained from one gallon of oil.

Another system, represented by the Blanchard lamps, utilises a self-contained lamp equipped with an inverted mantle, which is fed by paraffin vapour. It is claimed that one gallon of the quality of paraffin oil used in connection with this lamp will give an illuminating capacity of 18,000 c.p.-hours. An

ingenious and interesting device used in this lamp is the method of registering the level of liquid in the vaporiser. This consists of a magnetic needle on the outside of the vessel, which is affected by a movable iron piece within the vessel, rising and falling with the level of the liquid. The discovery of the inverted mantle has been a great boon to such systems of lighting on account of its greater strength and power of withstanding shock. It is also capable of greater adaptability, lamps yielding from 75 to several thousand c.p. being available.

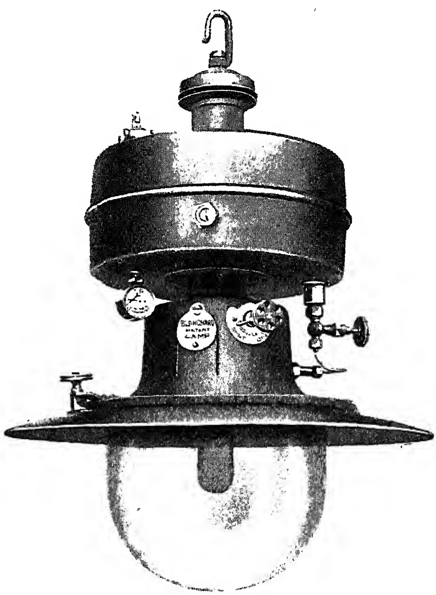


FIG. 51.—Blanchard incandescent paraffin lamp, commercial form.

Yet another form of lamp using liquid fuel is the Petrolite lamp, in which air is sucked through a porous material impregnated with suitable hydrocarbons, a draught being secured by the use of an exceptionally long chimney. An advantage claimed for this lamp is its safety. In spite of the high flame temperature necessary to bring the mantle to incandescence, the temperature of the lamp is stated to be actually lower than that of the surrounding air, and it is claimed that the lamp, if overturned, immediately becomes extinguished.

The lamp has been subjected to a variety of tests by Prof. J. T. Morris, who finds that a light of 40 c.p. is obtained by burning $1\frac{1}{2}$ ozs. of hydrocarbon per hour.

Incandescent oil lighting is widely employed for lighthouses, especially in remote situations, where a self-contained illuminant, not requiring excessive attention, is needed. It may also be applied to the solution of many new problems now arising in connection with aviation and the designs of signals for the guidance of aerial traffic.[1]

[1] Klebert, "Leuchtfeuer für den See und Luftverkehr," *Jour. f. Gasbeleuchtung*, 28th March 1914; *Zeitschr. f. Beleuchtungswesen*, 28th Feb. 1914.

ALCOHOL AND OTHER SELF-CONTAINED LAMPS.

Before leaving the class of self-contained lamps, some mention may be made of those using alcohol. A sketch of a typical lamp of this kind, taken from an interesting little book recently published in Germany,[1] is given in fig. 52. Alcohol has several advantages as an incandescent illuminant. Unlike petrol and petroleum, which consist in a mixture of somewhat uncertain composition of various hydrocarbons of different specific gravity, alcohol has a constant composition, consisting of liquid of the formula C_2H_5OH. This, theoretically, should make it easier to produce a perfect type of burner, and to secure complete combustion. In addition, alcohol is admittedly not a very inflammable liquid, and does not vaporise so readily; it has also the property of mixing with water, and is therefore readily extinguished by water. In many countries, again, there is no natural oil supply; but, on the other hand, the agricultural possibilities of the locality make it an easier matter to secure a supply of alcohol for illumination.

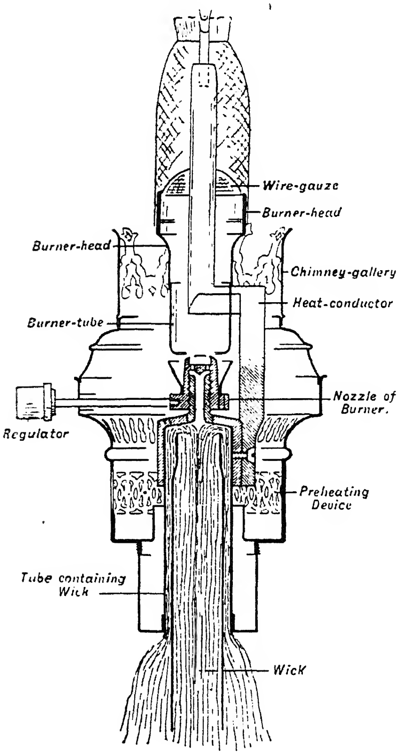


FIG. 52.—Alcohol incandescent lamp, with wick.

There are also a number of special systems of liquid fuel, such as Blaugas, Pintschgas, Wolfgas,[2] etc., which at one time had a considerable vogue for lighting railway carriages. In these systems various hydrocarbons are compressed and stored in cylinders, which can then

[1] W. Brüsch, *Die Beleuchtungswesen der Gegenwart.*

[2] *Illum. Eng.*, vol. i., 1908, p. 631; B. Monasch, *Licht und Lampe*, 24th Nov. 1912; A. Neuburger, *Licht und Lampe*, 4th July 1912; "Pintsch High-pressure Gas," *Jour. of Gas Lighting*, 6th Feb. 1912, etc.

be carried about to any desired destination. Some of the gases are credited with a very high calorific value, but it would seem that their use is more suitable in those cases in which portability is essential, and such illuminants as gas and electricity are not available, or only obtainable at prohibitive prices.

Petrol-air Gas Lighting.

We have next to consider two other systems of lighting—petrol-air gas lighting and acetylene—that have made great progress in recent years. These systems may be said to occupy an intermediate position between the methods of lighting by individual self-contained sources (oil lamps, candles, etc.) and gas and electricity, which are distributed from a central supply.

Petrol-air gas consists simply of air, to which has been added a small percentage of petrol vapour. The air-gas is generated by a small automatic plant, conveniently kept in a small outhouse, and it can then be led into houses and distributed by piping to incandescent burners in the same way as coal-gas. It will be observed that liquid does not exist in the pipes of the house, but only in the form of diluted vapour, in which the percentage of petrol present is invariably small ($1\frac{1}{2}$ to 6 per cent.). The success of the system is, however, entirely dependent on the choice of a suitable plant. There are said to be from 30 to 50 different types on the market in London alone.

Petrol-air Gas Plant.—The essential elements in any plant of this kind are a carburettor, in which the desired mixture of petrol vapour and air is produced; a holder, in which the gas is stored, and a compressor for the purpose of driving this gas through the pipes. The motive power may be supplied by a falling weight, hot-air engine, or water-power. The falling weight has the great advantage of simplicity. So long as the weights are off the ground the plant will continue to act and maintain the supply of gas, and a light is therefore available at any time during the night.

A hot-air engine occupies less space, is usually somewhat cheaper, and is more conveniently transferred from place to place. On the other hand, it requires a little attention to start it going. It is usually stopped during the night-time, in order to save the expense of continuous running, and in these circumstances a light cannot be obtained for any lengthy period without starting the engine, or by using a gas-holder of considerable size.

Water-power has advantages, but consumers are frequently debarred from using the mains direct, and it is unusual for any large quantity of stored water to be available.

A great deal of controversy has taken place on the respective advantages of "poor" and "rich" mixtures. It should be remembered, however, that even a so-called "rich" mixture is really very diluted and will hardly contain more than 6 per cent. of petrol. Mr E. Scott-Snell strongly advocates the use of such a mixture,[1] as being safer and enabling smaller pipes to be used.

On the other hand, some makers claim that with a "poor" gas (1½ to 2 per cent. petrol) a higher efficiency will be obtained at the burner.

Some makers, while recognising the desirability of keeping outside the explosive range, contend that 5 to 6 per cent. of petrol is a needlessly high proportion. There are also some who prefer an intermediate grade of gas (2¾ to 4½ per cent.) or who claim that their plant can be adjusted to give either a "rich" or a "poor" mixture as may be desired; for example, if the plant is intended for lighting purposes only, a 2 per cent. mixture is used; but for heating the value may be raised to 4½ per cent. or more. There are at the present time a great variety of petrol-air gas machines on the market. We must confine ourselves to describing one typical example, and in fig. 53 have reproduced a general view of the "County" plant.

From the diagram (fig. 53A) it will be noticed that the plant consists essentially of two bells which work in water seals. One bell is reciprocated by means of mechanism worked by the wound-up weight, and functions as an air-pump, taking in at each up stroke a given volume of air through the valve (T), and subsequently forcing this air down the pipe (K) into the other bell, and passing in *en route* through a carburettor (I). Attached to this air-pumping bell is a petrol-pump (G), in such a manner that at every stroke of the air bell there is a corresponding stroke of the petrol-pump. The petrol-pump discharges a measured amount of petrol through the pipe (P) into the carburettor, and this is evaporated by the measured air as it passes over it. The resulting gas fills the larger bell, which acts as a governor, maintaining the pressure in the piping system constant, and also regulating the action of the pumps; for when it is filled above a certain point, it operates a brake, which stops the air- and petrol-pumps from working. The gas is delivered for use through the central pipe (N).

There are one or two features in connection with the plant to which attention may be directed. It is claimed that the amount of air and the

[1] *Illum. Eng.*, London, Feb. 1913. See also Paper read before the Society of Engineers, 6th March 1911.

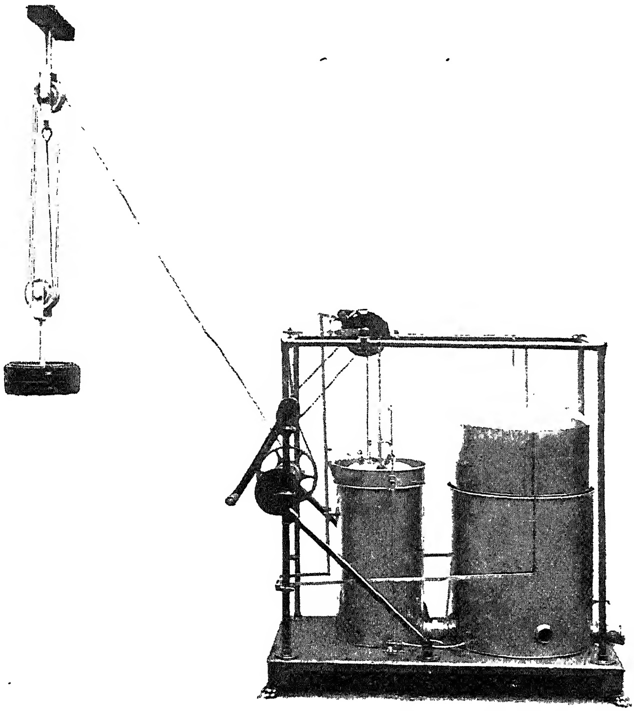


FIG. 53.—County weight-driven petrol-air gas plant; general view.

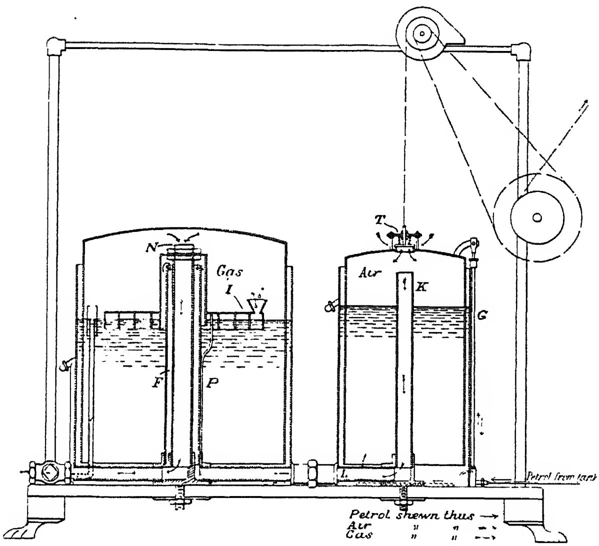


FIG. 53A.—County petrol-air gas plant; sectional view.
(T, air inlet; G, petrol-pump; I, carburettor; N, gas outlet; P, inlet pipe.)

amount of petrol supplied by a single stroke of the smaller bell are absolutely constant and definite; and that the charge of air always passes over its complementary charge of petrol at the same velocity, so that a gas of uniform mixture is supplied, no matter at what rate the demand may vary. Consequently the proportions of air and petrol vapour should be the same whether the machine only provides enough gas to make the small bell operate once a day, or is working up to its full capacity. This follows because a single stroke admits a volume of air fixed by the capacity of the bell, and a volume of petrol fixed by the capacity of the pump. An important point in the design of the plant is that all working parts are fully exposed to view, and immediately accessible.

The County plant utilises a comparatively rich mixture of 6 per cent. petrol and 94 per cent. air. The advantages claimed for this mixture, as regards safety, etc., have been alluded to above.

A good petrol-air gas plant should be absolutely automatic in action. Once it is started it should continue to generate gas of a uniform composition independent of the load or the external temperature, and should require practically no attention from the consumer beyond occasionally filling the petrol tank or winding up the weights. In many of the early machines this was far from being the case. For example, the quality of gas produced varied with the number of lights turned on, and the light suffered accordingly. This was sometimes due to the use of piping that was too small, and sometimes to defective carburetting. In the best modern machines the surface of petrol presented to a given surface of air in a certain time is maintained constant, with a view to producing a mixture of invariable composition.

Variations in the quality of gas generated may also arise through the use of an unsuitable variety of petrol, containing constituents which are sometimes present as vapour, but, when the temperature is lower, condense and play no active part.

Another defect that occasionally reveals itself in the inferior plants is the tendency to condensation of petrol in the pipes during cold weather—a condition which, besides interfering with the operation of the plant, may be a source of considerable danger. This fault may be due to the use of an unduly heavy petrol, the denser constituents of which deposit at a low temperature. Objection has been raised to methods of carburation involving the use of heat, the suggestion being that this practice may lead to the emission of a warm mixture containing hydrocarbons in suspension such as are not readily volatile at

winter temperatures. On a frosty evening these may condense in the relatively cool pipes.

Burners and Candle-power.—The incandescent burners used with petrol-air gas have to be specially designed for the purpose, the chief distinction from those used with coal-gas being that a considerably larger nipple is used; this is a distinct advantage, as such burners are naturally less liable to become choked with dust. The ideal type of burner depends on the composition of the gas; a burner intended for a rich mixture might not answer equally well with a poor one, and *vice versa*, although the adjustment of the air supply provides a certain latitude in this respect.

The fact of such large proportion of air being admitted through the pipes is favourable to complete combustion. Even at the low pressure of about $1\frac{1}{2}$ inches customary in petrol-air gas lighting, conditions approaching those characteristic of high-pressure gas lighting are obtained. A mantle of a given size should therefore in general have a higher intrinsic brilliancy than the same mantle employed with low-pressure coal-gas.

The Bijou type of inverted burners are very widely used for petrol-air gas lighting. The candle-power obtainable is variously stated by different manufacturers. Probably as much as 70 to 80 c.p. may be obtained from a new mantle under favourable conditions; but a mantle that has been in actual use for some time will more frequently be found to be yielding 40 to 50 c.p.

Such burners are stated to consume about $\frac{1}{130}$ of a gallon of petrol with the County plant, and it is possible that in favourable circumstances more economical results would often be obtained.

Burners having a smaller consumption than the above are occasionally used, but are stated to be less efficient in operation.

In conclusion it may be remarked that the type of plant should be selected judiciously. In country-house lighting particularly the machine should work automatically, requiring little or no adjustment. Expert assistance is often only obtainable from a considerable distance, should anything go wrong, and the plant will in general be attended to by people with little mechanical skill. The essential advantage claimed for petrol-air gas lighting is that the light is available at any time, just like gas or electricity. This is only possible in the case of a well-designed plant, and as there are at present about 40

to 50 different varieties on the market, some good but others quite the reverse, there is evidently need for discrimination.

It is interesting to note that a Petrol-air Gas Association has recently been formed in London, and no doubt its influence will be beneficial in promoting a more uniform standard of quality in the machines available.

ACETYLENE LIGHTING.

Acetylene has now become quite a familiar method of lighting, and many early difficulties against which it had to contend have been removed.

Acetylene gas was known to Sir Humphrey Davy as far back as 1836. Subsequently, in 1866, Berthelot, the great French chemist, interested himself in the subject. But it was not until about 1892, when Moissan described the manufacture of calcium carbide from a mixture of lime and carbon in the electric furnace, that acetylene came to be made on a practical scale. The discovery of the electro-chemical production of carbide was made practically simultaneously by Thomas Wilson in the United States and work in the same direction was carried out by the late Mr Worth in this country.

The change that takes place in the electric furnace may be approximately represented thus:—

CaO	+	$3C$	=	CaC_2	+	CO.
Lime.		Carbon.		Calcium Carbide.		Carbon Monoxide.

Acetylene, as is well known, is generated immediately water is brought in contact with calcium carbide according to the following relation:—

CaC_2	+	H_2O	=	CaO	+	C_2H_2.
Calcium Carbide.		Water.		Lime.		Acetylene.

Curiously enough, water, besides being necessary for its decomposition, is also indirectly responsible for the making of carbide. For the manufacture of carbide in large quantities demands cheap electrical energy, and is therefore most readily undertaken in countries where cheap water-power is available.

After the discoveries alluded to above, acetylene gas soon came to be known and used to some extent. But many early defects were only overcome by dogged perseverance. The gas

could not at first be obtained in a state of purity. The impurities contained were apt to cause the formation of a light "haze" or mist, and this effect was at one time quite a usual phenomenon in rooms in which acetylene was burned. Moreover, the range of mixtures with air over which explosion is possible is a wide one in the case of acetylene, and in the early forms of generating plant sufficient care was not always taken to avoid these conditions.

At the present time careful purification has removed these defects. It is now recognised as an essential feature that the generator should be kept cool, thus avoiding the tendency towards polymerisation. To-day it is possible to burn acetylene safely and without smell. Indeed it is said that the gas might be rendered absolutely odourless were it not that this might be a source of danger, owing to the fact that a leak might escape detection in its early stages.

Generating Apparatus.—To attempt any detailed description of acetylene generators would be without the scope of this work, and readers may be referred to several able treatises on the subject.[1]

Generators may be divided into two classes, "carbide to water" or "water to carbide"; these groups may be further subdivided into automatic and non-automatic.

At the present time many different types of generators are in use. In general, the application of water to carbide is preferred, especially in the case of automatic apparatus, mainly because the admission of water is so easy to control. Many small portable lamps and headlights for cycles and motor cars, etc., come under this heading. Automatic plants are now preferred for sustained lighting on a large scale; the water to carbide method is almost invariably used with this type of plant, owing to the certainty of action and to recent improvements in methods of purification.

An acetylene plant consists of the following constituent parts:—

(1) *The Generator proper* contains the carbide, and is divided into compartments in such a way that the charge in one compartment is exhausted before water is admitted to the next. In this way it is easy

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[1] *Acetylene, its Generation and Use*, by F. H. Leeds and W. J. A. Butterfield; *Das Acetylen*, by J. H. Vogel; *Annuaire International de l'Acétylène*, R. Granjon and P. Rosenberg.

to ascertain on inspection how much gas is still obtainable. In modern installations it is customary to provide two duplicate generators, either of which can be put into action by merely turning a tap. In this way it is possible in an emergency to continue supplying gas from one generator while the other is being attended to and recharged.

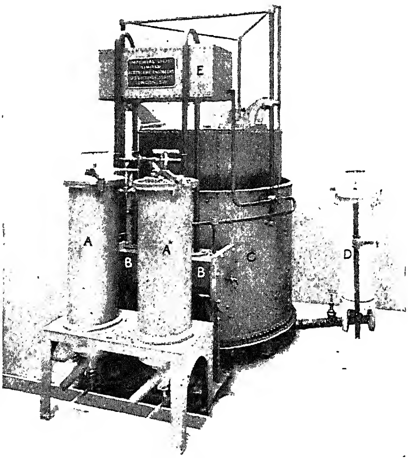


FIG. 54.—An "Imperial" acetylene generator, general view.

(2) *The Washer*, which consists essentially of a piece of apparatus, forming as a rule the lower part of the generator, through which the gas is caused to pass on its way to the gasholder, and is "scrubbed" and partially purified in doing so.

(3) *The Water-supply Tank*, containing the water fed to the carbide. This is automatically controlled by the aid of a piston actuated by a projection in the gasholder, which, in its descent, is automatically caused to admit more water as the supply of gas begins to get exhausted, or by any other appropriate mechanical device.

(4) *The Gasholder* serves to collect the gas when it comes through the washer from the generator. Besides storing the gas and cooling it

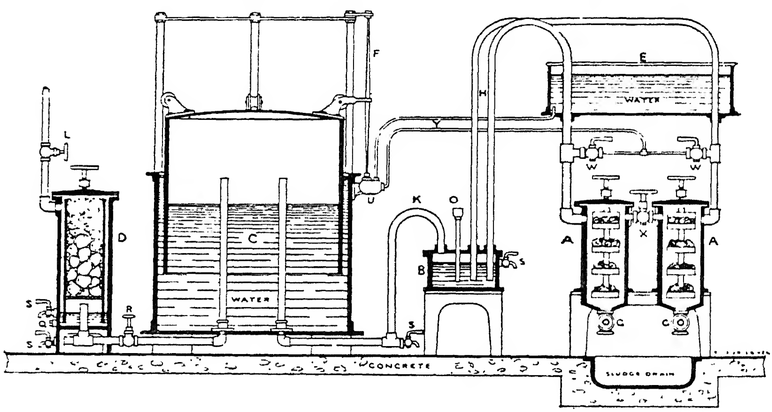


FIG. 54A.—An "Imperial" acetylene generator, sectional view.

after its treatment by water in the washer, the gasholder serves to regulate the pressure of the gas supplied to the house.

(5) *The Drier and Purifier* is placed between the gasholder and the pipes, and serves to dry and thoroughly remove the last traces of phosphorated hydrogen and other impurities that may still remain in the

gas after leaving the gasholder. After passing through this apparatus the acetylene is fit for actual use.

The general nature of a modern acetylene plant will be understood from figs. The principal parts are A, generator; B, washer; C, holder; D, purifier. When the plant is in action water flows from the tank (E) into the generator (A) through the valve (U). The acetylene produced passes through the washer (B) into the bell at C, causing it to rise.

When the holder is about half full the control tap is automatically turned off and no more gas generated. As the gas is used up the bell falls and turns on the tap again, so that gas is generated once more. This automatic action continues until the carbide is exhausted. Meantime the gas stored in the holder passes out into the purifier (D) preliminary to consumption.

It will be observed that two "twin" generators are shown. If necessary one of these can be charged while the other is still in operation. One of the taps (W) would then be closed, putting this corresponding generator out of action. The cover of the generator would then be removed, the sludge run off through the cock (G), and the interior cleaned out, and a fresh charge of carbide inserted. The drain pipes (S, S, S) serve to run off any accumulated water.

An additional modern development worthy of mention is the use of briquettes, which are composed of granular carbide compressed into cakes and covered with some inactive binding material. It is claimed for such briquettes that they only evolve acetylene when in actual contact with water, and when withdrawn immediately cease to do so. They are therefore useful in avoiding the tendency to "after-gassing" (*i.e.* the gradual liberation of gas after the generator has been turned off).

In addition they are said to be non-hydroscopic, and therefore do not require to be stored in sealed tins to avoid deterioration, as is the case with ordinary carbide. This special granular carbide is conveniently used for motor-car headlights, portable table-lamps, and other small generators of the non-automatic type; it is, however, naturally somewhat more expensive than the ordinary variety.

The piping necessary for acetylene gas will usually be considerably smaller than that required for coal-gas. Consumers may be advised to secure the very best workmanship in the entire installation. Acetylene, like petrol-air gas, is used to a great extent in remote situations, where expert assistance is not readily available. A cheap and inferior installation may be a constant source of trouble and annoyance. Many reputable firms will undertake to execute any repairs within a given period after installation, thus making themselves responsible for the plant being in good order.

Burners.—An interesting comparison may be drawn between the burners used for petrol-air gas and acetylene respectively. For petrol-air gas much larger burner apertures must be used than in the case of coal-gas. For acetylene gas the exact contrary is the case. Owing to its high illuminating power the aperture in the burners must be exceedingly small, and this proved a difficulty in the early stages of acetylene lighting. The burners readily became stopped up and required constant cleaning.

This sooting effect was due largely to impurities in the gas, as well as imperfect design of the burner. The introduction of steatite in place of metal was a great improvement. Modern types of burners should last for years. The form most usually

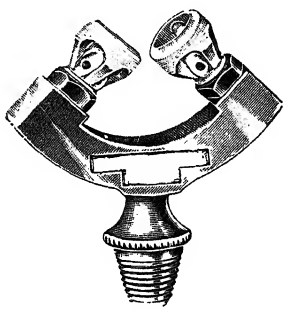


FIG. 55.—Bray Elta twin burner.
(Has 2 jets impinging on one another.)

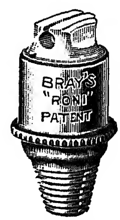


FIG. 56.—Roni burner (with slot).

employed is the "cross jet," the two flames playing on one another at an angle. This arrangement is conducive to high temperature and improved efficiency, and is also said to assist in preventing sooting of the burner. On the other hand, this form is not always best for searchlight and projector work when the flame is near to polished glass surfaces. For, if one of the jets becomes stopped up, the flame from the other one may shoot out and impinge upon the glass surface, causing it to crack. For this class of work burners of the Roni type, consisting of a single fairly big slot-aperture, are therefore preferred to those having cross jets. They are less likely to get choked up.

The ordinary range of consumption of acetylene burners is from $\frac{1}{8}$ to 1 cubic foot of gas per hour, the usual pressure being about 4 inches. The efficiency obtainable is variously stated, but may be taken at about 25 to 30 candle-hours per cubic foot. (It should be noted that this figure presumably refers to the intensity

in a horizontal direction.) One may expect to obtain roughly 5 cubic feet of gas per lb. of carbide.

Acetylene, being burned as a luminous flame, has the advantage—somewhat exceptional in these days of incandescent illuminants—of being readily controllable at the tap, so that a wide range in candle-power can be attained. Attempts have been made to use the gas with incandescent burners, but it is doubtful whether much has yet been gained in this way. An efficiency as high as 100 c.p. per cubic foot is said to have been obtained, but the small apertures used in the burners are liable to become stopped and give trouble.

The incandescent method, however, appears to have distinct advantages for cinematograph work, when an oxy-acetylene flame can be concentrated on a small but by no means fragile pellet of refractory material. Mr C. Hoddle, in his recent paper before the Illuminating Engineering Society,[1] gave his experiences with this new light. The disc on which the flame plays is only 22 mm. in diameter, and the fact of the light being concentrated within such a small area is naturally advantageous for optical work. With such a lamp, consuming 7 cubic feet per hour of a 50 per cent. mixture of acetylene and oxygen, an equivalent candle-power over 1000 was stated to be obtained.

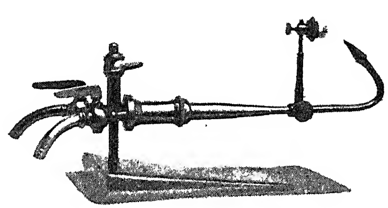


FIG. 57.—New oxy-acetylene projector lamp, using about 7 cubic feet per hour of a mixture of oxygen and acetylene.

At a distance of 18 feet this gave over 1000 c.p., and the light, being concentrated over a small area, is convenient from an optical standpoint.

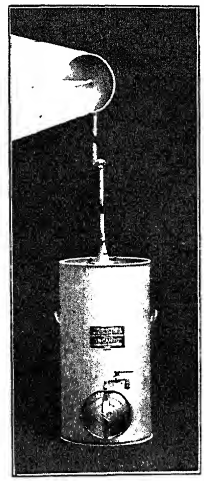


FIG. 58.—Acetylene flare light and generator.

When lamps of high candle-power are desired (*e.g.* in lighting railway stations) it may be necessary to employ a cluster of

[1] *Illum. Eng.*, London, vol. vi., Feb. 1913, p. 67.

burners each consuming $\frac{1}{2}$ to 1 cubic foot of acetylene. For emergency or spectacular lighting acetylene "flares" are often convenient. A flare consists simply of a portable generator connected by a large burner equipped with an approximately parabolic reflector, so as to throw the light strongly in one direction. The generator, when fully charged, should supply a light for six hours, consuming about 12 lbs. of carbide while doing so. It is difficult to give the value of the light from an arrangement of this description with any precision, but it is stated to give about 1000 c.p. As a rough rule for spectacular lighting, Mr Hoddle suggests employing about four flares for every 1000 square feet to be illuminated.

Dissolved Acetylene.—Very early in the history of acetylene

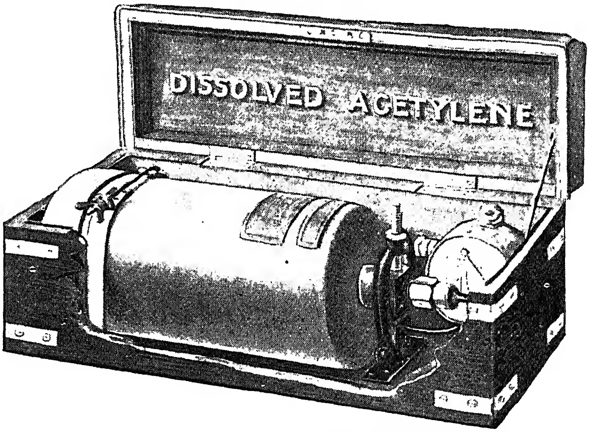


FIG. 59.—Typical dissolved acetylene outfit (suitable for motor cars, etc.).

attempts were made to store the gas under pressure. But considerable difficulty was experienced in making the process entirely safe. Eventually the problem was solved by the aid of the organic liquid acetone, which possesses the remarkable faculty of dissolving about 240 times its own volume of acetylene at a pressure of 10 atmospheres and a temperature of 15 degrees. A vessel of acetone, saturated with acetylene at this comparatively low and safe pressure, will therefore liberate 216 times its own volume when the pressure is reduced to the ordinary atmospheric value.

Dissolved acetylene outfits have a number of important applications. They are used in connection with oxy-acetylene welding, for motor-car headlights, and for the illumination of

motor 'buses. In the United States they have also been used to some extent for train lighting. There are also possibilities for its use for cinematograph work in connection with the new oxy-acetylene incandescent projector lamp referred to above. It is, however, desirable that the films used with such apparatus should be of a non-inflammable type.

The convenience of dissolved acetylene for emergency light-

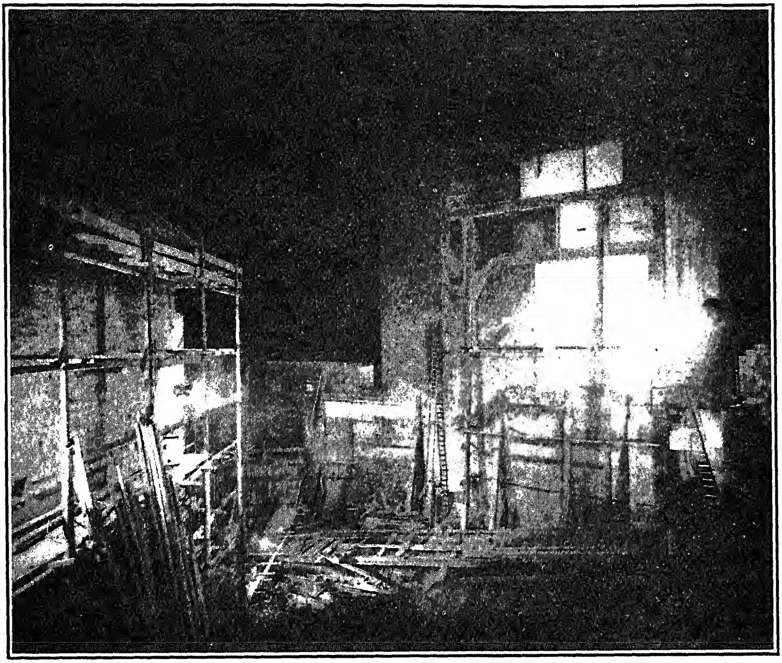


FIG. 60.—Showing portable acetylene flares in use for illuminating a building in course of construction.

ing is evident. One has only to connect the cylinder and release the pressure. After use the cylinder can be readily removed to be filled again, a charged one being substituted. The smallest size of cylinder in general use will store about 6 cubic feet of acetylene, the cylinder being about 1 foot long and 4 inches in diameter. Larger cylinders containing up to 100 cubic feet are also available.

Special Uses of Acetylene.—Acetylene is employed in much the same circumstances as petrol-air gas lighting, *e.g.* in country houses and remote districts where gas and electricity are not

available. In fact, the two illuminants are keen rivals i
field of illumination.

There are also many special uses for acetylene, arisin
the ease with which a powerful light can be produced a
notice. An instance is afforded by the use of acetylen
for night construction work. In the erection of buildin
mending of roads, etc., such flares are very convenient a
widely used. Occasions also arise when, owing to the
of the regular illuminant, emergency lighting is neede
here again the portable acetylene generat
proved its value. For example, it has bee
for emergency lighting at special fêtes in ch
and for country fairs, and it was recently em
at the Pantheon in Paris on the occasion
Rousseau centenary. Neither gas nor elec
has been led into the building, and it was
ently only at the last moment that the auth
remembered that there were no arrangemen
artificial light. Fortunately, the situatio
saved by the use of acetylene flares.

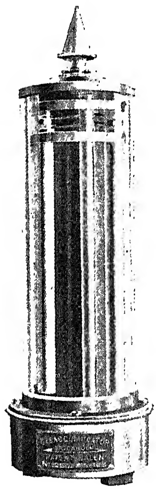


FIG. 61.—Aga (Dalen) sun valve.

Acetylene, and other self-contained illumi
would seem to have special fields of utility i
time, when troops moving by night have to d
on their own resources for illumination. P
flares and lamps would be valuable for fiel
pitals, tent-lighting, and for searching ou
wounded on the field of battle. It might
prove of use for aëroplane searchlights, where the dom
factor is the amount of light (lumen-hours) available for a
weight of apparatus.

But perhaps the best example of the special uses of ace
is its employment in navigation for the lighting of buoy
beacons. Canada, Sweden, the United States, and other cou
having an extensive and irregular coast-line make consta
of acetylene in their mercantile marine. Canada especiall
used it very largely for the buoys on her great rivers.
and beacons in remote situations may be charged, light
and left alone for months at a time and continue to fu
their light unattended.

Through the genius of Mr Gustav Dalen of Stockholm
most valuable automatic devices for controlling the light
these buoys have been contrived. The Dalen sun valv

example, automatically arranges for the light to be furnished during the night-time, but entirely extinguished (with the exception of a small by-pass) during the day. The working of this device is based on the unequal expansion of two sets of rods, one of which is coated black and therefore absorbs all solar radiation, while the other is highly polished and reflects it. During the daytime there is a difference in temperature, and hence unequal expansion in the rods; this closes the valve,

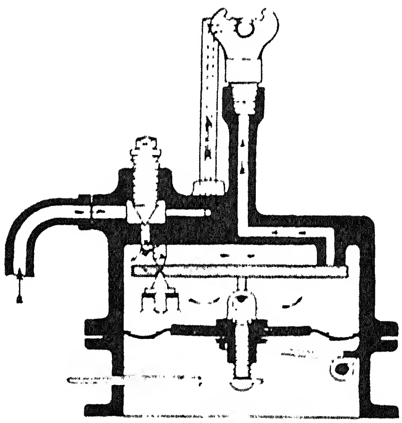


FIG. 62.—Aga (Dalen) flash-light valve.

Gas enters by means of pipe shown at left hand side, and through the regulating valve, a portion passing to the pilot-burner through the by-pass channel.

Gas entering the flasher distends the diaphragm, which then exerts a pull upon the magnetised valve tongue, shown in section, covering the exit to the main burner.

When the downward pull of the diaphragm finally draws the valve tongue away from the mouth of the gas exit, the gas escapes to the main burner, and the diaphragm returns to its normal position when all the gas is discharged. The valve then recovers the exit and the cycle is repeated.

The rate of flow of gas into the flasher is regulated by the valve in the admission passage, and the length of stroke in the diaphragm (which is exceedingly small) is adjusted by means of the screw passing through the centre of the diaphragm.

leaving only the small by-pass burning. During the night, however, the temperature of both sets of rods remains the same, and under these conditions the light is kept on. Naturally this arrangement enables a very substantial saving in gas to be made and extends the period of time before recharging is necessary.

Another ingenious automatic device depends on the flow of gas into a measured vessel. At a certain pressure all gas except that flowing through the by-pass is cut off, but is readmitted after a certain interval. An automatic flashing light is thus

obtained, and the periods of brightness and darkness can be readily adjusted. This enables a considerable saving of gas to be made. For instance, a flash of a duration of one-third of a second every third second would lead to a saving of 90 per cent. Yet the value of the light for signalling purposes would not be impaired thereby. It is well known that an intermittent light, besides being readily identified by the period of the flashes, can frequently be seen at a further distance than a steady one.

Experiments with these ingenious flashing acetylene lights have been made on the Swedish State railways. Apart from the natural advantages of acetylene for signal lighting, it is claimed that the flashing method is a valuable additional means of distinction on the complicated multiple lines, where all the available colours have already been utilised. For example, the main-line signals may be readily distinguished by the fact of their flashing, while the others are burning continuously; it is claimed that for high-speed traffic this is often a better means of distinction than difference in colour would be.

Quite recently the Road Board have been experimenting in London with flashing signs of this kind. It has been suggested that they might advantageously be used to indicate crossings, obstructions in the roadway, sudden turns, etc., and would have the merit of being readily visible by night. The use of acetylene for illuminating sign-posts has also been debated. For country roads some form of self-contained illuminant is of course desirable, and the acetylene equipment would probably only require renewal at intervals of a few weeks. The maintenance of such signals could doubtless be attended by the R.A.C. scouts who already patrol the roads in the respective districts.

In 1912 Gustav Dalen was awarded a Nobel prize in recognition of his work in connection with maritime signals. It is sad to relate that an accident has since deprived him of his eyesight; that light is now withheld from one whose life-work consisted in giving light to others.

CHAPTER V.

ILLUMINATION AND THE EYE.

Construction of the Human Eye—Analogy with a Camera and Photographic Plate—Amount of Illumination necessary to see Detail, and to perceive Light and Shade—"Glare" and Violent Contrast, and their Avoidance—Intrinsic Brilliancy of Illuminants—Weber's Rules for avoiding Glare—Reflection from Shiny Paper—Effect of Colour on Acuteness of Vision—Physiological Effects of Coloured Light—Influence of Invisible Radiation—Ultra-Violet Rays—Light and General Hygiene—Conclusion.

In previous chapters we have considered the existing methods of producing light by means of gas, oil, acetylene, electricity, etc. On modern illuminants, as we have seen, a great deal of skill and ingenuity has been expended and remarkable advances have been made. But it is a little curious to observe how little consideration, relatively, has been paid to the effect on the eye of the light we have been at such pains to produce.

For, after all, it is through the eye that all our impressions on illumination are received. A method of lighting which strikes the eye as distasteful and unpleasant will always be considered unsatisfactory, however efficient as regards mere creation of brightness and economy in energy consumption it may be. In short, it is to *the eye* that the ultimate appeal in illuminating engineering must always be made.

The Construction of the Eye.

Seeing that the behaviour of the eye is so important in lighting matters, it may be well to give a brief sketch of its construction. An analogy has often been drawn between the action of the eye and that of a photographic camera. In both cases we have two distinct appliances to consider, the optical system by which the light is collected and directed, and the sensitive surface on which the image is received and the impressions

recorded, only in the case of the eye both these appliances are of a much more delicate and complicated nature.[1]

Fig. 63 will perhaps serve to show in section the general nature of the eye. The light entering it passes first through a transparent curved surface known as the cornea, C. It must then pass through a series of three transparent refracting elements, L_1, L_2, and L_3. Of these, L_2 is known as the crystalline lens, and is composed of transparent horny material. On either side of it are refracting media of a less solid nature. L_1 is an anterior chamber filled with transparent aqueous material, L_3 a chamber filled with gelatinous material, also transparent. These three media together form a complex lens system whose function it is to form an image on the sensitive layer, the retina, at the back of the eye. The construction of these retinal layers is extremely complex, and readers who desire fuller particulars may be recommended to study one of the many available physiological treatises on the eye. One of the most interesting features is the layer of minute light - percipient organs known as the rods and cones. These terminate in a series of delicate fibres and cells by which the retina proper is brought into connection with the nervous system. In among the rods (and also, according to some authorities, among the cones) there flows a pigment known as the visual purple. This is bleached by light, and evidently plays an important part in responding photochemically to the luminous image received on the retina, creating the impression which is ultimately telegraphed to the brain.

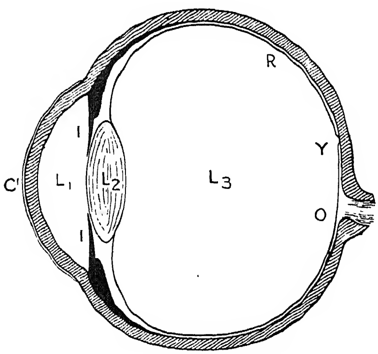


FIG. 63.—Diagram of the eye.

O. Optic nerve and "blind spot."
C. Cornea.
I I, Iris diaphragm.
L_1, Aqueous humour.
L_2, Crystalline lens.
L_3, Vitreous humour.
R. Retina.
Y. Yellow spot.

It will be seen that the purely optical system of the eye is of a complicated nature. It has the additional advantage over the camera lens of being adjustable, so that it can focus both near and distant objects. This is accomplished by the ciliary muscles attached to the lens, the tension of which can be increased or relaxed, so that the lens assumes a thinner or more bulgy form according as its focus requires to be lengthened or shortened. This effort is termed accommodation. The ordinary

[1] See also "The Physiological Aspects of Illuminating Engineering," by Dr P. W. Cobb, *Lectures on Illuminating Engineering*, vol. ii. p. 527, Johns Hopkins University, Baltimore, 1911.

, besides being able to see distant objects clearly, can also ust itself so as to obtain a clear image of objects at distances less than about 10 inches—by means of a temporary severe ·rt sometimes for even smaller distances. Some people, howr, are unable to make the effort required to focus near objects, l are then said to be "long-sighted," a condition commonly t with in old age. Others can see near object's clearly, but are ıble to distinguish distant ones, and they are then said to be ıort-sighted." There are other lens defects, such as astigman, which interfere with clear definition of the retinal image. o these we need not enter, but it will be readily understood t any continuous strain imposed on the eye by poor illuminan is detrimental. For example, if the illumination on the ge of a book is insufficient there is a tendency to bring the nt nearer and nearer to the eyes in the effort to make out letters, and this constant near work naturally tends in ırse of time to produce short sight. In the same way it will understood that exposure of the delicate retinal surfaces to y bright lights may also be prejudicial.

In front of the crystalline lens L_2 there is another piece of paratus which serves to make the analogy with the camera ll more complete. This is the iris diaphragm, I, which covers great part of the lens, so that only the central portion, the pil, is commonly utilised. The iris thus resembles the stop ed with a camera lens, but here again we find that it differs om the photographic apparatus in being automatic. The aphragm can adjust itself to the light, leaving a larger or ıaller central aperture according to circumstances. There e many different conditions which affect the size of the pupil. is different in various individuals, according to the state of eir health and according to the kind of work which the eye is lled upon to perform. But from our standpoint the most important function of the iris is to shield the eye against excess of ght. The effect of coming from a dark room into bright ırroundings is to cause an immediate contraction of the pupil, ıus cutting down the amount of light entering the eye and ving the retina time to adjust itself to the new conditions. he most striking quality of the eye, indeed, is its power of laptation, and in illuminating engineering our aim must be to low time for these processes to take place; we must avoid iolent contrasts and fluctuations, which are outside its range of djustment and therefore give rise to discomfort and fatigue.

There are two points on the retina which deserve mention. At O there is an opening in the layer through which the optic nerve passes, and it appears that the eye is incapable of seeing an image which is received at this point. It is therefore called the "blind spot."

The other thing of interest is a small depression at Y, termed the *macula lutea* or yellow spot. At this particular point the acuteness of vision is a maximum, and it has been suggested that this is due to the fact that on the yellow spot there are mainly cones and comparatively few rods; while at its very centre, the *fovea centralis*, there are only cones, which are also exceptionally small and fine. As we approach the more remote part of the retina, on the other hand, we find that the number of cones in comparison with rods becomes smaller, while at the extreme periphery there are only rods and no cones.

As mentioned previously, many curious facts have been observed regarding the behaviour of these organs, which appear to play an important part in accounting for the peculiarities of the eye at high and low illuminations. It was formerly assumed that the cones were responsible for vision under ordinary circumstances, and that vision in very weak light was carried on exclusively by the rods. According to the latest theories, however, it appears that the cones are always the light-percipient organs, and that the rods have merely a secondary function of distributing the visual purple.

In any case there can be no doubt but that the condition of the eye when it has been exposed for a long time to darkness or feeble illumination is very different from what it is when subjected to bright light. The "dark-adapted" eye apparently sees colours in a different way, and common experience teaches that it is vastly more sensitive. When we emerge from bright sunlight into deep shadow our eyes are at first unable to make out the surrounding objects at all. In course of time they become clearer, but this process of adaptation to environment may require a considerable time to be complete. In the same way, when one returns to bright surroundings the glare is at first intolerable, but eventually, as one becomes used to the new range of brightness, the eye becomes "light-adapted," and one is no longer dazzled. On the other hand, it will be readily understood that it is possible to have objects of such exceeding brightness that the eye cannot, within a reasonable period of time, adjust itself and accordingly suffers. There is reason to

suppose that the daylight-adapted eye is in a very different state from the eye experiencing the relatively low order of illumination met with by artificial light. This may explain some of the apparent anomalies in our impressions of daylight.

The process of adaptation is accomplished partly by the aid of the iris diaphragm, which quickly closes when the eye is exposed to a bright light and opens in darkness, thus varying the amount of light admitted to the retina. But a great part of the process of adaptation takes place in the retina itself, and proceeds more slowly. The change is accompanied by movements of the visual purple. In the dark-adapted eye the pigment is allowed to spread all over the retina, in the light-adapted eye it retreats from the extremities of the rods away from the light.

The Amount of Light necessary in order to see Detail.—Yet, while it is doubtless true that when the eye is allowed to adapt itself to a feeble light its power of perceiving detail is substantially increased, it is of course a matter of common experience that a certain amount of light is in practice necessary in order to see objects clearly. The amount necessary will depend to some extent on the state of the eye. But it appears possible to state an order of illumination when the eye has become apparently more or less "saturated," so that any further increase in illumination produces relatively little effect.

One of our first and most important problems as lighting engineers should therefore be to establish some form of standard for the amount of illumination required by the eye in daily life. Experience shows that some kinds of work require more light than others. A higher illumination is needed for very fine sewing than for reading large type. But a first approximation may be derived from the recorded investigations of physiologists on the variation of acuteness of vision with increasing illumination.

Our ability to see things seems to depend on two distinct factors. There is, firstly, the perception of *form.* Clearly the sharpness of printed letters will depend on the perfection of the optical system of the observer's eye. No amount of light would enable a person to see an object clearly if his eye lens could not be so adjusted as to bring it into focus. An extremely short-sighted person, for example, cannot as a rule be helped out of his difficulty by very brightly illuminating the object examined. On the other hand, the average person requires under normal conditions a certain amount of light to read type

clearly, and once this value is attained a further increase of illumination is of little service.

Secondly, there is the perception of light and shade. If an object were of exactly the same colour and brightness as its surroundings it would be indistinguishable from them (a fact which, as is well known, is unconsciously utilised by those animals whose colour eventually comes to resemble that of surrounding objects so as to make detection of their presence difficult). The percentage change in tone which can be detected by the human eye (known as Fechner's fraction) varies according to the individual and the order of illumination. It appears that under favourable conditions a difference of less than ½ per cent. should be perceptible. Tscherning, however, mentions a case of a man who could barely detect 10 per cent., and found it difficult to see his way about.

Thirdly, there is the complicated question of the perception of colour. In this respect individuals differ very greatly, and something will be said on this point in a later chapter. For the moment the point we desire to emphasise is that this faculty, like the two referred to above, demands for its proper exercise a certain amount of illumination.

The explanation of the curious changes in colour-vision which occur with diminishing illumination is still a matter of dispute among authorities. It may be mentioned, however, that in fading light some colours persist longer than others. With a very feeble illumination blues and greens still appear luminous when a bright red has become jet-black. (This effect may be excellently observed by watching the changes in appearance of a bed of geraniums fringed with grass while the daylight is gradually fading.) Ultimately in a very weak light the eye loses all power of perceiving colours. Everything appears an uncanny grey. It is true that Professor Burch has found that after waiting sufficiently long in a dark room the power of seeing colours by feeble light appears to return to some extent. But the process is apparently a very slow one.[1]

There are on record quite a number of independent researches illustrating the connection between illumination and acuteness of vision. The effect of light on the perception of form (reading fine print, etc.) was studied exhaustively by Uthoff in Germany.[2]

[1] *Proc. Roy. Soc. London*, 1905.

[2] Graefe's *Archiv*, xxxii. 171; xxxvi. 33. Helmholtz, *Handbuch der phys. Optik.*, p. 426.

A more recent set of practical investigations has been made by Laporte and Broca.[1] Various standard sizes of type were illuminated by modern illuminants, and the authors determined the variety of type that could just be read by a specified illumination.

In fig. 64 we reproduce a curve based on these data, connecting the acuteness of vision and the illumination in foot-candles. It will be seen that soon after the illumination falls to less than half a foot-candle a most rapid diminution in our power to perceive detail occurs. On the other hand, once we arrive at about 2 to 4 foot-candles we find that the increase in illumination afterwards produces only a small increase in acuteness of vision. Laporte and Broca therefore agree with other authorities in suggesting that for reading average type an illumination of not less than 3 to 4 foot-candles (approx. 30 to 40 lux) is necessary.

The classic researches on the perception of light and shade are those of Koenig and Brodhun, who determined the percentage change in brightness detectable by the eye for a very wide range of illumination and for white, blue, and red light.[2] For the sake of comparison we reproduce part of their curve in fig. 65, and it will be at once evident how broadly similar it is to that shown in fig. 64.

Many other tests have been carried out on this point. For example, the results of some experiments carried out with a Lummer Brodhun photometer on an ordinary bench was described by one of the writers[3] before the Illuminating Engineering Society in 1910, and led to substantially the same results. From these and many other researches we shall probably not be far wrong in concluding that as far as ordinary vision is concerned the eye has arrived at a fairly stable condition when an illumination of 3 to 4 foot-candles is provided. There are, nevertheless, instances of fine work in which minute detail or objects of almost exactly the same tone have to be distinguished, or surfaces used which are dark in texture, where an extra strong illumination would be desirable.

There do not appear to be on record many experiments deliberately designed to test the connection between the power of detecting fine shades of colour and the illumination. It would be rather difficult to express this in quantitative form. There

[1] *Bull. de la Soc. Int. des Électriciens*, June 1908.

[2] *Sitz. Akad. zu Berlin*, 1888, p. 917.

[3] *Illum. Eng.*, London, vol. iii., 1910, p. 237.

are, however, researches on colour-photometry which show pretty clearly that the "Purkinje effect" and other oddities of colour-

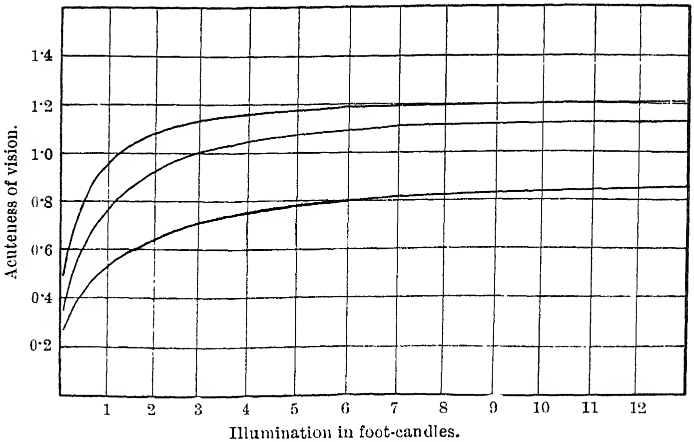


FIG. 64.—Curves showing how acuteness of vision in various individuals is affected by increased illumination (Laporte and Broca).

vision become accentuated at weak illuminations,[1] and that a fairly stable state of things would in general be arrived at when an illumination of 3 to 4 foot-candles was provided.

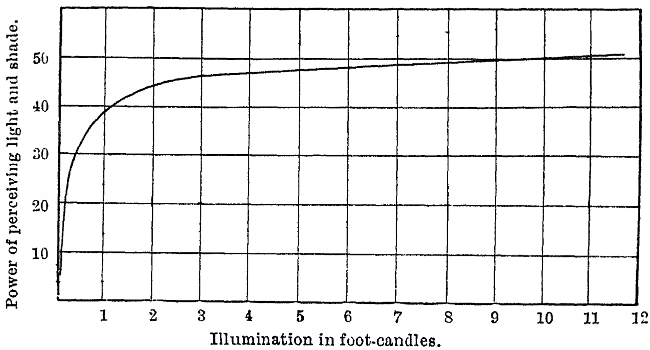


FIG. 65.—Curve connecting the "power of perceiving light and shade" $\left(\frac{I}{dI}\right)$ with the illumination (Koenig and Brodhun). Under favourable circumstances the eye can detect a change in brightness of less than one per cent. $\left(i.e.\ \frac{I}{dI} > 100\right)$.

This value therefore furnishes a rough estimate of the minimum illumination required by the eye for its normal functions, although still higher illuminations might often be

[1] See, for example, Dow, *Proc. Phys. Soc.*, London, vol. xxii. p. 60.

profitably employed. Koenig and Brodhun have shown that with illuminations of some thousands of foot-candles an effect of dazzle may be produced which leads to a *diminution* in acuteness of vision.

Exposure of the Eye to Violent Contrast and "Glare."—In what has been said above we have considered the first important requirement of the eye—sufficiency of illumination. We now pass on to an equally vital point—avoidance of excess of light.

In describing the structure of the eye it was pointed out how marvellously it is adapted to accommodate itself to changes in brightness. It is possible for men to endure the glare of the sun in the tropics on the one hand, and the gloom of the coal-mine on the other. But the transition from one set of conditions to the other must be gradual and not abrupt, for the process of adaptation requires time.

In lighting, violent contrasts should almost always be avoided. The result of seeing something very bright immediately after something relatively dark (successive contrast) may be very discomforting to the eye. Everyone is familiar with the sensation of shock experienced on stepping from a dark room into the bright sunlight, or even an interior brilliantly illuminated by artificial means. Some minutes elapse before the eye can become accustomed to the new surroundings, and the constant repetition of the experience would be very fatiguing. It is for this reason that a fluctuating or flickering light is so intolerable for reading. The nerves controlling the pupil aperture and the retina of the eye are constantly endeavouring to fall in with the changing conditions and failing to do so. In the same way Dr Bell [1] has suggested that the method of lighting shown in fig. 66 should never be practised.

When the table or desk is brightly illuminated, and the remainder of the room is left in dense shadow, the eye undergoes a process of sudden adaptation every time the gaze is transferred from the bright paper to the more sombre surroundings. To many people reading in a room so lighted is very wearisome. On the other hand, one is inclined to suppose that it would not be desirable to go to the other extreme, and to aim at a monotonous even brightness. The best plan would probably be to distribute the highest illumination on the table for the work, but also to provide a moderate value all over the room.

[1] "The Physiological Basis of Illumination," *Proc. Am. Acad. of Arts and Sciences*, Sept. 1907, vol. xliii. No. 4.

So far we have spoken of successive contrast. But the eye is also troubled by excessive "simultaneous contrast," *i.e.* when several objects of widely different brightness are visible at the same time. Moreover, there are many objects, such as the naked arc light, which are probably too bright to be looked at continuously, whatever their surroundings may be. Many instances have been recorded of severe inflammation of the eyes following incautious exposure to powerful illuminants at close quarters, and it is well known that the glare of the sun reflected

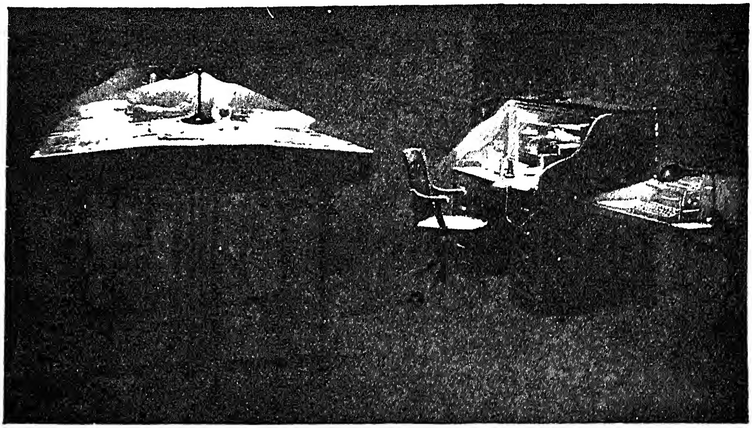


FIG. 66.—Example of excessive contrast in desk lighting.

from the sea, from snow, or even from the white road may have a similar effect.

This leads us to refer to the discussion which took place about two years ago before the Illuminating Engineering Society (London) on the subject of "Glare."[1] This term is perhaps a little difficult to define precisely, but is now almost invariably used to describe conditions of excessive brilliancy such as are trying to the eye.

The glaring effect in artificial lighting is almost always connected with the exposure to the eye of bright unscreened sources of light. The primary object of light is to illuminate our surroundings, to enable us to see the page of a book, a picture, the walls of a room, etc., and the brightness of such comparatively mildly illuminated surface is well within the range of adaptation of the eye. The sensation of glare is experienced when one sees at close quarters the intensely bright surface of

[1] *Illum. Eng.*, London, vol. iii., 1910, pp. 99–130, 169–190.

the illuminant itself. Everyone is aware that it is injudicious (and indeed for most people impossible) to do more than glance at the sun. Nature has therefore provided our eyes with the shelter of the brow and lashes, and under ordinary circumstances these completely screen the eyes from the direct rays. Yet in lighting rooms artificially people not infrequently place unscreened brilliant illuminants in such positions that it is difficult for the eye to escape them. The result is a sense of weariness and fatigue. It must be remembered that the perception of such objects takes place through the formation of an intensely bright image on the retina. The effort of the retina and the photochemical pigment to accommodate themselves to this extreme local brilliancy is very severe, sometimes impossible. Prof. Burch has mentioned that in the course of some experiments on colour he deliberately focussed coloured light on his eye, rendering it temporarily colour-blind. The scientific experience was doubtless valuable, but the result was that for years afterwards there were certain exhausted regions of the retina which led to grey patches in the field of vision. By prolonged exposure to intensely bright lights at close quarters permanent injury to the retina may be done, and when once the range of normal adaptation has been passed recuperation is often very slow. Fortunately, extreme cases of this kind are not common. But the reader can easily satisfy himself as to the existence of transient but highly inconvenient dazzle caused by unshaded and carelessly placed lamps. If the eyes are directed for a short time towards the unscreened filament of an incandescent lamp and then turned towards a dark background, a distinct "after-image" can often be seen. This frequently changes colour and becomes gradually fainter as the process of retinal recuperation takes place, but if the observer goes into a dark room the image can be seen for much longer. According to Prof. Burch, it is only after waiting for several hours in complete darkness that all traces of dazzle disappear.

The question therefore arises, what ought the limiting brightness of objects in an ordinary artificially lighted room to be? This is a somewhat complex question. It may perhaps be well at this stage to give a table of the "intrinsic brilliancy" of various objects Some of these figures are the results of actual measurements by the authors, others are taken from the published tables of authorities on this subject. It is now generally recognised that the chief factor in giving rise to an

impression of glare is not so much the total amount of light given by a source, as the manner in which this light is concentrated over a small area. For example, if 50 c.p. were spread over 1 square foot, the retina would probably find little difficulty in adapting itself to this order of brilliancy; but when this same amount of light is concentrated over the small dimensions of a metallic filament, the image formed on the retina appears painfully bright. The degree of concentration of the light is conveniently expressed as the candles divided by the area of radiating surface of the source, and this quantity is termed intrinsic brilliancy.

TABLE I.—INTRINSIC BRILLIANCY OF VARIOUS ILLUMINANTS.

Source.	Candles.	Superficial Area. *	Intrinsic Brilliancy.
		Sq. Inches.	Candles per sq. inch.
Pine splinter	5	4	1·2
Roman oil lamp	0·8	0·2	0·4
Candle	1	0·4	2·5
Rape oil lamp	1–10	0·2–2	5
Petroleum	5–15	1–3	5
Gas, flat flame	5–25	2–5	2–5
Argand	30	4	7·5
Acetylene	25	1–2	10–25
Gas, (incandescent):			
Low pressure	10–80	1–3	10–30
High pressure	100–1500	2–5	50–300
Electric incandescent:			
Carbon filament	16	0·04	400
Metal "	32	0·04	800
Electric arc lamp (naked)	...	...	20,000 (approx.)
Holophane globe surrounding metal-filament lamp (av.).	...	...	0·5–1·0
Dense opal globe surrounding metal-filament lamp.	...	...	0·1–0·5
Heavy silk shades, Chinese lanterns, etc., covering small incandescent lamps, candles, etc.	...	...	0·01–0·2
Average brightness of sky	...	...	2·5

* Apparent area calculated in direction of maximum candle-power. The figures given in this table are naturally only approximate.

It will at once be seen how vastly the intrinsic brilliancy of many modern illuminants exceeds that of the older sources of light, the flat-flame gas-burner, the oil lamp, and the candle. Some authorities, arguing that the candle-flame has about the highest intrinsic brilliancy (about $2\frac{1}{2}$ c.p. per square inch) to

be observed with comfort at close quarters, have suggested that all sources used in this way should be so screened that their brightness does not exceed this value. Curiously enough, the average intrinsic brilliancy of the sky is about the same. Now, under average climatic conditions the white sky is about the most brilliant surface which is seen constantly, and presumably our eyes have developed to this limit. This, therefore, suggests another reasonable ground for fixing the minimum permissible intrinsic brilliancy near 2 to 3 c.p. per square inch.

It does not seem a very difficult matter to keep the intrinsic brilliancy of sources exposed in the direct range of vision down to this value. The brightness of an opal shade completely screening an electric glow-lamp, for example, will usually be found to be in the neighbourhood of 0·1 to 0·5 c.p. per square inch only. Some writers have suggested that 2 to 3 c.p. per square inch is still excessive, and that in small rooms a limit of 0·1 c.p. per square inch is really necessary.

But it is quite clear that caution is needed in imposing limits of this kind. Conditions which are offensive and glaring to some eyes are apparently not so to others. We must also bear in mind the effect of adaptation of the eye. Even a lighted match will appear glaring to a person suddenly waking in the night. Again, a lamp which would seem insufferably bright at one's elbow may be quite inoffensive when it is hung near the ceiling of a large room. The nature of the background to the bright source is important. An unscreened filament, seen against a dark wall or curtain, seems distinctly more trying than when its background consists of a white diffusing material.

In the case of lamps placed at one's elbow it is usually advisable to use an opaque shade, which throws as much light as possible on the object illuminated, but completely conceals the source itself from the eye. But in many cases, particularly in a large room where the lamps are hung high up near the ceiling, the exposure of the mantle or filament occasions much less inconvenience; the brow shades the eye from the direct rays of light, just as it protects them from the sun. It should, however, be remembered that in most cases the use of a reflector is economical, quite apart from its function of screening the illuminant from the eye, because it serves to direct most of the light downwards, where it is chiefly needed.

One of the most definite series of rules drafted for the

avoidance of glare is that proposed by Prof. L. Weber of Kiel.[1] As an illustration of the general precautions to be aimed at they are instructive, but it will naturally be understood that even these rules cannot be applied rigidly to all circumstances. According to Prof. Weber an installation may be "glaring"—

(*a*) If the ratio of the intrinsic brilliancy of the source of light to that of the illuminated surroundings exceeds a certain limit. This ratio should not exceed a value of about 100.

(*b*) If the absolute intrinsic brilliancy of the source exceeds a certain value. The brilliancy of the open candle-flame (about $2\frac{1}{2}$ c.p. per square inch) might be taken as the safe limit.

(*c*) If the angle between the direction of vision of the eye when applied to the work it is called upon to do (*e.g.* when gazing at a desk, blackboard, or diagram on the wall, etc.) and the line from the eye to the source of light is too small. This minimum angle might be provisionally assumed to be 30°.

(*d*) When the extent (apparent area) of the illuminating body is too large. The source should not subtend an angle of less than 5° at the eye.

In considering glare one may naturally allow more latitude in some cases than in others. For example, in a school or a library one would naturally take special precautions to avoid anything liable to distress the eyes. It is not too much to say that in these cases *no* bare mantle or filament should be visible to readers or scholars. On the other hand, in a restaurant, while discouraging the offensive and vulgar display of a multitude of bare lamps, one must remember that a certain amount of mild sparkle may sometimes be desirable. The same, of course, applies to street decorations, although even here the finest effects are secured by exercising a certain restraint. In shop lighting a distinction should be drawn between the uses of bright lights for advertisement and for window lighting. In many cases bright outside lamps are insisted on, and the best that can be done is to secure their arrangement at such a height as to achieve their spectacular purpose without dazzling those who wish to see into the windows. But it will be found that in the highest class of shops, methods of lighting by concealed sources, similar to those used on the stage, are superseding mere brilliance. In almost any lighting problem a good rule to follow is "light on the object, not on the eye."

There are some other effects which are sometimes included under the heading of glare. Dr Ettles has referred to the effect

[1] *Illum. Eng.*, London, vol. iii., 1910, p. 116.

of light entering the eye and undergoing reflection to and fro by the various optical surfaces. This tends to produce a luminous mist, which is superimposed over the main image and thus interferes with its sharpness. The effect appears to be accentuated when the eye looks at an excessively bright object; it may perhaps help to explain the great inconvenience of being able to see a light "out of the tail of the eye" at the same time as one is trying to read a photometer. According to Stockhausen, the presence of ultra-violet rays in an illuminant tends to produce fluorescence of the eye lens, and this again gives the impression of a luminous haze, which interferes with the clearness of vision.

Another form of glare is produced by direct reflection from shiny paper. Some of the highly glazed paper used for art printing is particularly trying, and in children's books, particularly, a matt variety of paper is to be preferred. At present, unfortunately, "art" paper is regarded as essential for the very best reproduction of fine half-tone blocks; but some of the matt art papers now available give very promising results.

In cases in which reading or writing on more or less shiny paper is constantly going on, it is desirable to scheme out the system of illumination specially with a view to avoiding direct reflection. When local lamps are employed, the angle at which the rays strike the paper should be carefully selected. Unless care is taken, local lighting may be conspicuously bad in this respect. When general lighting is provided, it is desirable to use a distributed series of small well-shaded units. Indirect and semi-indirect methods, which carry this subdivision of units still further, are particularly advantageous in this respect.

Acuteness of Vision by Light of Various Colours.

Something may next be said regarding the effect of coloured light on the eye. On this we shall have something to add in the next chapter. For the moment we may confine ourselves to the question, what abnormal physiological effects, if any, are likely to be occasioned by the differences in colour met with in artificial illuminants?

Unfortunately, there seems to be little trustworthy information yet available on this point. The eye, as we know, is only sensitive to a single octave of vibrations—from the extreme violet ($0{\cdot}4\mu$) to deep red ($0{\cdot}8\mu$)—and these colours are present in varying degree in the case of artificial illuminants. Yet, taken

as a whole, the composition of the artificial light from commercial sources does not differ so much as might be supposed; what we usually get is something equivalent to "white light," with a slight admixture of some predominant tint. Claims are not infrequently made for one or another illuminant that it is "less trying" to the eyes, but these are not infrequently of a vague and conflicting nature. One so often finds on examination that it is the manner in which the illuminant is used, rather than the quality of the light itself, that is at fault. The statement so freely made at one time that "electric light is bad for the eyes" seems to have originated rather in the misuse of the comparatively bright electric filaments, their exposure at close quarters without proper methods of shading, and the resultant glare rather than in any defect in the quality of the light. The colour of the light yielded by the electric incandescent and arc lamp, the incandescent mantle, acetylene, and other illuminants is in each case considerably different from that of the old oil lamp and the candle. Yet it cannot be said that there has yet been proved to be anything physiologically wrong with the colour of any of these illuminants, provided they are used in a reasonable and judicious way. Some doubt may perhaps be felt regarding the results of continuous exposure of the eyes to the more peculiarly coloured sources, such as the mercury-vapour lamp. One might imagine, for example, that the colour-sense of people who habitually worked by a light of this kind would be affected. But the matter does not seem to have been tested out thoroughly as yet, and we have little definite evidence.

It has been suggested that some lights give better definition than others, *i.e.* that objects illuminated with a certain brightness appear sharper and better defined in some cases than in others; and that some illuminants are better than others for reading and close work. The existence of such an effect is conceivable but there is little evidence to show that ordinary commercial illuminants differ very widely in this respect, This seems to be the conclusion of Laporte and Broca,[1] who have studied the matter with some care. In the case of *monochromatic* light there would seem to be evidence of more marked differences.

The researches of Koenig and Brodhun (*loc. cit.*) on the perception of light and shade suggest that at very weak illuminations there is greater sensitiveness for blue light than for red, but that at moderate high illuminations there is little difference to be

[1] *Bull. Soc. Int. des Électriciens*, June 1908.

seen. It would appear that such difference as is found is merely due to the fact that at very weak illuminations the brightness of the blue would appear the greater. Repetition of their experiments with a Lummer Brodhun photometer has shown that, *for a given subjective brightness*, there is little difference between these colours as regards perception of tone.[1]

But in the case of perception of *form* we find that another factor comes in, namely, the want of achromatism of the eye. Tscherning, Helmholtz, and other physiological authorities have long ago drawn attention to this peculiarity of the eye, and Shelford Bidwell many years ago pointed out that the average eye is habitually short-sighted for violet.[2] The ordinary eye-lens is unable to focus light of widely different colours simul-

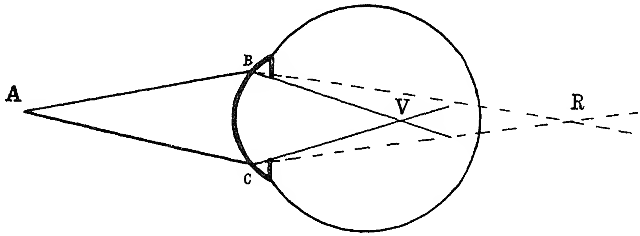


FIG. 67.—The rays of white light from A are split up at B and C, the red rays being focussed at R behind the retina, and the violet rays at V in front of the retina.

taneously. Thus if A be a luminous point its rays are split up on reaching the eye at B and C. The violet light is brought to a focus, say, at V, while the red focus is further back at R. Yellow rays would be assembled on the retina intermediate between these two points. Evidently the eye cannot adjust itself so as to see all these colours equally sharp at the same time.

The usual experience seems to be that whereas there is not much difference between the sharpness of objects illuminated by light of different colours for near vision (because the observer can accommodate by a strong effort), at a little distance things illuminated by the blue end of the spectrum appear quite blurred. A line spectrum thrown upon a screen seems to spread out like a fan at the violet end; and black lines on a white ground, illuminated by a mercury-vapour lamp screened with dense blue glass, can be made to disappear completely at a little distance.

[1] Dow, *Illum. Eng.*, London, vol. iii., 1910, p. 238.
[2] *Curiosities of Light and Sight*, by Shelford Bidwell, pp. 95–97.

In general, therefore, one would expect the red end of the spectrum to be best for illuminating clocks, signs, and notices to be seen at a distance, while green or even blue light might be best for very near work.[1]

When observing objects illuminated by ordinary white light our eyes probably accommodate for the most luminous central part of the spectrum, while the light in the extreme red and violet in general tends to "fuzz" and blur the image. A distinctly sharper image, it is said, can be obtained by using monochromatic light. It might therefore conceivably pay us sometimes to block out the rays which cannot be focussed; by so doing we should obtain less light, but better definition. For example, experiments conducted by one of the writers on the mercury-vapour lamp have led him to the conclusion that the eye cannot accommodate for the yellow, green, and violet rays simultaneously, and that better "seeing power" would often be obtained by interposing a screen to cut off the blue and violet rays.

This question of using monochromatic light to improve acuteness of vision has also been investigated by Luckiesh. He, too, finds that monochromatic light will in general be better than white light for the purpose, and that yellow rays ($0{\cdot}58\mu$) in general give maximum visual acuity.[2]

Physiological Effects of Coloured Light.

Let us now turn to the so-called physiological effects of coloured light. On this point very little is known. Our eyes, it is true, seem to be most sensitive to light in the central region of the spectrum, the green-yellow. Waller has shown that photochemical action is most readily produced by light of this kind, and more recent researches on luminous efficiency seem now to have established the point of maximum sensitiveness with fair precision. On either side of this point the effect on the retina becomes less, and in the extreme red and violet it requires an exceedingly large amount of energy to produce any impression of light at all. One would therefore expect that exposure to large quantities of pure red or violet light, such as one seldom meets in nature, would produce peculiar effects. But it is by no means easy to produce radiation of this kind in large quantities, and little seems to be known definitely regarding their effect on

[1] Dow, *Illum. Eng.*, London, vol. ii., 1909, p. 233.
[2] *Elec. World*, 18th Nov. 1911.

vision. Steinmetz has expressed the view that red light is particularly fatiguing, and that the pupil aperture of the eye is expressly designed to protect it against excess of this kind of radiation.[1] According to this theory the pupil aperture should react much more readily to the red and infra-red than to other regions of the spectrum. This, however, does not appear to have been confirmed. Some experiments were carried out by one of the authors in conjunction with Mr V. H. Mackinney, and later also with Dr W. Ettles, on this point, and it appeared that the contraction, in so far as it was affected by light, depended more on brightness than colour. This is in accord with the experience of Haycraft,[2] who obtained flash-light photographs of the pupil of an eye, placed successively in the various regions of the spectrum. The greatest effect was produced in the yellow, where the luminosity is also most intense.

Very peculiar are the influences upon mental conditions attributed to visible light of different colours. Let it be clearly understood that many of these effects about to be described require verification, and can hardly be accepted as scientific fact. But many of these speculations on the influence of coloured light are so interesting—and illustrate so aptly the contention that light has an intimate effect on health—that they cannot be entirely passed by.

It would seem that we have become accustomed to associate certain colours with certain sensations. We speak of the colours at the red end of the spectrum as "warm" and those at the violet end as "cold." This association, however, seems to be psychological in origin. For most heat-giving processes have, in the past, been associated with the red and orange shades. It is only recently that we have been able to secure sufficiently high temperatures to render the blue end of the spectrum prominent. The flaming torches of the ancients, the coal fire and the charcoal brazier, the oil lamp and the candle—all these sources of light and heat are rich in the hues of the red end of the spectrum.

Naturally, therefore, we have come to associate the idea of warmth with the red and orange hues of firelight and artificial illumination, and the converse idea with the blue shades of twilight, heralding the approaching night and the coldness without.

[1] "Light and Illumination," address before the Illuminating Engineering Society, U.S.A., *Illum. Eng.*, New York, Dec. 1906.

[2] Schäfer's *Physiology*, vol. ii. p. 1078.

But we also associate an idea of excitement and stimulation with the warm hues, which is absent from the colder shades.

The exciting influence of the red rag upon the bull is seemingly not confined to this animal. We ourselves constantly select red as the symbol of the passions and of exciting and irritating ideas. It is this influence which has led us to choose this colour as the symbol of danger and war.

Many curious instances of the exciting influence of the red shades and the converse effect of the so-called cold shades have been reported. The influence of red light is stated to be at first bracing, and persons exposed to its influence become cheerful and animated. Eventually, however, if the exposure is unduly prolonged, this mental state gives place to a condition of irritation, and may even develop into a species of delirium.

Blue and violet light, on the other hand, are said to exert a soothing and subduing effect, and therefore may also be of a beneficial character, . . . may, for instance, prove of use in relieving insomnia. But in this case also, if the exposure is too prolonged, the initial soothing influence may become depressing, rendering the person acted upon melancholy and dreamy. Indeed, the confinement of prisoners in rooms from which all but blue light had been excluded is said to have exerted a permanently injurious and "benumbing" effect upon the mental faculties, rendering them incapable of making any strong effort.[1]

The popular expression "to be in the blues" thus apparently rests upon a scientific basis.

These qualities of red and blue light are said to have proved of benefit in the treatment of many cases of insanity. According to Dr Ponza of Piedmont, cases of mania, where the excited behaviour of the patient calls for restraint, are quieted by exposure to blue light. Cases of melancholia, on the other hand, which call for a tonic, benefited by exposure to the stimulating red light.

The author referred to above quotes several other cases of the peculiar influences of red and blue light. One such case was that of the workers in the photographic works of the "Maison Lumière." Much of the work carried out was done under the influence of red light; it was then found that the workers became very excited, gesticulated, and sang, but the substitution of a different form of coloured glass had a quieting

[1] See *Light Energy*, by M. A. Cleaves, p. 600.

effect and they then returned to their normal tranquillity (*Light Energy*, p. 591).

Some very interesting illustrations of the physiological effects described in this chapter may also be derived from the study of the influence of light on plant life.

When one recalls that Siemens as long ago as 1880[1] drew attention to the remarkable results which could be secured in this way, it seems strange that horticulturists should still make such little use of these effects at the present day, when artificial light can be produced so much more cheaply.

Siemens showed that the continuous application of intense light not only enabled the plant to stand a greater temperature, and so to make better growth, but in itself promoted a luxuriance of foliage, an intensity of colouring, and a rapid ripening of fruit beyond that obtainable under ordinary conditions.

By experiments under glass of different colours, too, he came to the conclusion, as other investigators have done, that the red and yellow rays in the spectrum are most efficacious in producing the decomposition of carbon dioxide by the vegetable cell and in assisting growth.

He also found that an excess of ultra-violet energy produced an unfavourable influence on plant life.[2] For the light from a naked arc light caused the leaves of plants, upon which the rays impinged directly, to shrivel and wither away. But by the introduction of a screen of plain glass between the source and the plants experimented upon, the injurious rays were absorbed and further trouble was avoided.

Some other interesting instances of the influence of light on plant life were given about the same date by Schübeler,[3] who drew attention to the influence of light upon the colour and aroma of plants.

The extraordinarily rapid growth of vegetation in the Arctic regions during the long period of uninterrupted sunshine which follows the Arctic winter has often been remarked; and also the rapid ripening of corn in regions of Norway and Sweden, where the summer does not exceed two months, but where the sun during this period scarcely sets.

As a curious illustration of the effect of light on the lower forms of life, we may recall the connection between the abund-

[1] *Proc. Roy. Soc.*, clxxxviii. p. 210.

[2] *Brit. Assoc.*, 1881, p. 475.

[3] *Nature*, 29th Jan. 1880.

ance of sunlight and the mackerel industry traced by Mr J. Martin Duncan in a lecture before the Royal Society of Arts (London).[1]

It appears that these fish feed largely on a certain vegetable organism, and their prevalence during the fishing season depends on the amount available for consumption. Now these organisms can only develop fully in periods of light sunshine. Consequently, during the years when there is an undue preponderance of dull, cloudy days, the vegetable organism is scarce, the mackerel which feed upon it do not frequent the coast in such great numbers, and the fishing industry accordingly suffers.

Very remarkable are some of the recent results of M. Camille Flammarion,[2] who attempted the culture of "sensitive" Mimosa plants under the influence of light of different colours.

At the end of a few months the plants placed in blue light had scarcely gained in growth at all. They appeared, too, to be in a "benumbed" and comatose state, and exhibited none of the sensibility to touch normally characteristic of these sensitive Mimosas.

But the plants grown under red light were four times as big as those grown under ordinary white light, and fifteen times as big as those grown under blue light. In addition to this they had developed well-marked flower-balls, which the other plant had not even begun to do, and were in an acutely sensitive state.

Here, therefore, we have another illustration of the peculiar (and possibly excessive) stimulating effect of the red end of the spectrum, and the converse deadening effect of the blue rays. The general effect of radiation on life has been strikingly treated by Steinmetz.[3]

According to his view, it would appear that the red, orange, and probably the yellow rays, by assisting the photo-resonance and building up of complex organic chains of molecules, stimulate plant life.

The visible blue rays, on the other hand, exert a soothing influence, produce insensibility, and arrest the progress of life without actually destroying it.

[1] 20th March 1912.

[2] *Bulletin de la Société Astronomique de France*, Aug. 1897 ; see also article by G. Clarke Nuttal in the *Fortnightly Review*, April 1907, p. 723.

[3] Address before the Illuminating Engineering Society in the United States, Third Annual Convention, 1909.

But the ultra-violet rays, when present in any but small quantities, seem to cause resonance of the individual atoms on atomic systems, break up the complex molecules, on the interaction of which the very existence of life depends, and so cause death.

Influence of Invisible Radiation.—So far we have spoken of the effect of visible rays. But, as will appear in the next chapter, artificial illuminants also produce large quantities of non-luminous radiation, and it remains to inquire what effect these vibrations have on the human eye. On either side of the restricted range of visible waves of light there is a vast region which the eye cannot see. Rays beyond the deep violet (of shorter wave-length than about $0{\cdot}4\mu$) have a frequency higher than visible light, and are known as "ultra-violet." These rays are known to be instrumental in causing chemical action. As hinted above, photochemical action seems to be mainly a matter of optical resonance. If the atoms of the substance acted upon, or the electrons of which they are composed, possess a natural period of oscillation comparable with that of the wave attacking them, they are set into rapid vibration, break up, and recombine in a more stable form, and chemical action occurs.

The visible rays seem to possess too great a period to cause resonance of any but very complex groups of molecules, and the radiations of larger wave-length and slower frequency than the visible vibrations (known as the "infra-red") are presumably even less active in this respect. But in most artificial illuminants they form far the larger part of the energy produced, so that any effect they *do* exert deserves to be taken into account.

The chemical activity of the ultra-violet rays is now well established. These rays play an important part in photography, cause coloured pigments and materials to fade, and have now been shown to have a marked destructive effect on certain kinds of bacteria. Sunlight is often exceptionally rich in these rays. Sunburning is now understood to be due to them, and not, as might naturally be supposed, to the heat. The rays of short wave-length are absorbed to a great extent by the earth's atmosphere, and particularly in cloudy weather. But with a clear sky, and in high altitudes, the ultra-violet rays are more potent. Mountaineers have to take special precautions to avoid excessive inflammation of the face and eyes.

One very curious illustration of this effect is the marking of the skin in smallpox. As far back as the thirteenth century

it was known that the scars of this disease were much milder if the patient was kept in a room hung with red curtains. Only after the work of Finsen, in the last century, was it generally recognised that the red curtains were effective because they obstructed the ultra-violet rays. At the present time, however, it is known that such curtains are not the only means (nor the best) of achieving this end, and other precautions are adopted.

At the same time it need not be supposed that ultra-violet rays are necessarily prejudicial. In excess they presumably are, but in moderation they have useful functions. The bronzing of the skin is frequently an indication of health, and "sun-baths" and light-baths of various kinds now form an integral part of medical treatment. In treatment of skin diseases, too, ultra-violet rays appear to be beneficial; and in the Finsen light, which has proved so efficacious in treating lupus, such rays seem to play an important part.

Besides affecting the skin, excess of ultra-violet light appears to be irritating to the eyes. The researches of physiologists suggest that the snow-blindness frequently experienced by mountaineers in high altitudes is largely due to the exceptionally strong ultra-violet element, although the reflection of the visible rays of the bright sun from the snow in itself has doubtless a contributing effect.

During the last few years a number of artificial illuminants have made their appearance which are exceptionally rich in ultra-violet rays. Some of them appear to rival and even surpass direct sunlight in this respect. Experience has shown that incautious exposure to such illuminants at close quarters may also have bad effects. For example, it is a common experience, after exposure to a naked arc light for some time, to suffer from inflammation of the eyes and peeling of the skin. The mere fact of receiving an image of such great concentrated brilliancy on the retina would naturally be prejudicial, but the trouble seems to be accentuated by the large proportion of ultra-violet energy. One of the writers, for instance, has met with a case in which an ordinary carbon arc was used for weeks without injury. But when, for the purpose of some experiments, an iron-cored electrode was introduced inflammation immediately followed. Experience has also shown that the arc formed in the process of cutting and welding iron electrically is very rich in ultra-violet rays, and is apt to give rise to trouble unless complete

precautions as regards screening the eyes are taken. An interesting illustration of this kind is afforded by some experiments at Niagara Falls on 29th December 1901, when a powerful 350-amp. arc was used to bore through an iron plate. Everyone who witnessed the experiment afterwards suffered from inflammation of the eyes, with the exception of two men who happened to be short-sighted and wore glasses. In subsequent work masks in which white stonecutter's goggles had been mounted were employed, and no further trouble was experienced.[1]

Thick glass is impervious to the shortest ultra-violet rays, and this affords another reason for screening modern powerful sources so that the direct rays are not received by the eye. On the other hand, clear glass, and even the blue glass customarily employed, does not seem to be sufficient protection for near work with the latest and most powerful sources of ultra-violet light, such as the quartz tube mercury-vapour lamp, and special observing screens are here advisable.

The cataract experienced by glass-workers has also been attributed to the ultra-violet radiation from the molten glass in the furnace, but it seems probable that the intense heat is also a contributing factor.

It has been pointed out that there is a certain tendency in modern illuminants towards richness in ultra-violet light as well as great intrinsic brilliancy. Even the ordinary illuminants, the metallic-filament lamp and the incandescent mantle, contain considerably more ultra-violet energy than the old flat-flame gas-burner and the candle, and there are certain other sources which seem to be quite exceptionally powerful. This has led Schanz and Stockhausen to undertake a very elaborate investigation into the effect of ultra-violet rays.[2] In addition to the evidence of their ill effects in causing cataract and snow-blindness, etc., these observers mention that the concentration of ultra-violet rays on the eye-lens causes fluorescence and even a turbidity which may develop into complete opacity. They have also found that ultra-violet rays may be grouped into three classes, (1) those between $0{\cdot}35\mu$ and $0{\cdot}4\mu$, which cause the eye-lens to fluoresce, but also reach the retina, where they may exert prejudicial action; (2) those between $0{\cdot}3\mu$ and $0{\cdot}35\mu$, which are practically entirely absorbed by the lens; and (3) those of wave-

[1] *Phototherapy*, by Morell, p. 472.

[2] *Elektrot. Zeitschr.*, 13th Aug. 1908; *Illum. Eng.*, London, vol. iii., 1910, p. 181. See also Klein, *Gesundheits-Ingenieur*, No. 15, 1912.

[illegible] which do not penetrate the eye to any [illegible] responsible for inflammation of the outer eye, [illegible]

[illegible] effect of exposure to ultra-violet rays, the [illegible] the outer eye, is thus caused by the rays of [illegible] wave-length which are readily absorbed by ordinary [glass]. But the two other varieties ($0{\cdot}3\mu$ to $0{\cdot}4\mu$), it is [suggested], may be responsible for more deep-seated injury, and [illegible] not absorbed by ordinary glass to any great extent. [Schanz] and Stockhausen have therefore produced a form of [glass (which they] term "Euphos") which has the property of [absorbing] ultra-violet radiation while being comparatively [transparent] to visible rays. Luckiesh has recently given the [absorption curve] of this glass throughout the visible and ultra-[violet spectrum], as compared with various other varieties. [Spectacles] composed of Euphos glass are said to be very [effective] in preventing snow-blindness, and it has also been suggested that lamp-bulbs and chimneys might with advantage be made of this material. For close observation work with powerful lamps this glass may well be combined with a dark variety excluding most of the visible light.

The question of making glasses to cut off excess of visible, infra-red (heat) or ultra-violet radiation has since been taken up very thoroughly by Sir William Crookes. He describes a great variety of glasses some of which are stated to be opaque to ultra-violet rays and yet to have only a slight coloration, transmitting 70 to 90 per cent of visible light. These researches were undertaken in connection with the Cataract Committee of the Royal Society of London.[1]

While there seems general agreement as to the need for precautions when powerful sources are used at close quarters, and of adequate screening of commercial illuminants containing any large proportion of these rays, opinion still seems divided as to whether any injury is likely to be caused by their presence in daily life. Proper methods of shading should go far to remove any such danger. Voege[2] has suggested that if this is done the effect of ultra-violet light merely reflected from surfaces in the ordinary way should not give rise to any inconvenience. He points out that a surface illuminated by daylight will frequently not only be brighter, but will also reflect a larger amount of

[1] *Phil. Trans.*, Series A, vol. ccxiv., 1914, pp. 1–25.
[2] *Elektrot. Zeitschr.*, 13th Aug. 1908.

ultra-violet energy than is likely to be derived in this way from any artificial illuminant at present in use. Yet we have not hitherto regarded daylight as harmful. Luckiesh[1] and L. Bell[2] have published researches leading to substantially the same conclusion. Moreover, while excess of ultra-violet rays is doubtless prejudicial, there appears good ground for supposing that their presence in small quantities is beneficial, and even necessary to health. Reference has been made to their action on the skin, and it seems probable that they play a part in combating the germs of many diseases. An interesting historical summary of researches into their destructive effect on bacteria has recently been given by Bujwid.[3] The explanation of the well-known prejudicial effect of excluding sunlight from rooms, and even of keeping the glass windows continually closed, seems to lie partly in the exclusion of these germicidal rays. It may also be mentioned that ultra-violet energy has found quite an important field of application for the sterilisation of water (destruction of cholera germs, etc.), and one of the writers was assured by a fruit-grower in the north of England that he had found these rays most useful for checking fungoid diseases of plants.

Very little is known regarding the effect of the infra-red rays. It is well known that close proximity to sources which yield an abnormal amount of heat produces uncomfortable sensations, such as a sense of tension of the forehead, a dryness of the skin and eyes, and a tendency to shed tears. One of the few records of investigations on this subject is supplied by Ballner.[4] Here, again, it is evident that one of the most important points is to prevent the direct rays of light entering the eye. But conceivably even the light reflected from paper, etc., might be trying to the eyes if a very large proportion of heat rays were present. Ballner mentions a case of an incandescent burner in which an illumination of more than 11 to 16 foot-candles proved inconvenient in this respect. But it is doubtful if this conclusion could be applied in the case of modern burners, and the matter requires fuller confirmation. While referring to this question we may also recall the long controversy that has raged round the effect of gas lamps on

[1] *Elec. World*, 15th June 1912.
[2] *Ibid.*, 13th April 1912.
[3] *Jour. f. Gasbeleuchtung*, 2nd Sept. 1911.
[4] See *Illum. Eng.*, New York, June 1906.

... air in confined rooms. Comparative ... and electricity have been instituted and have ... results.[1] But much remains to be done in ... repetition of experiments by different observers ... Taking a broad view, it may be said that ... the incandescent burner has done much to ... formerly urged against gas lighting with ... of the atmosphere, undue heating, and formation ... in rooms. In modern well-ventilated rooms, ... forms of lamps, no inconvenience in this ... experienced. On the other hand, circumstances ... met with in which the entire absence of products ... and the confinement of the illuminant in an air-... advantageous and even essential, and it may then ... to use incandescent electric lamps.

... the impression left by the available records of ... into the effect of light on the eye is somewhat incon-... A considerable number of minute researches of a purely ... and physiological character have been carried out, but ... difficult to draw general conclusions applicable to daily life. A ... series of references to papers on this subject was given by Mr Herbert T. Parsons in a recent paper at the Seventeenth International Medical Congress, held in London in 1913.[2] The subject has also been considered by a research committee appointed by the Illuminating Engineering Society in the United States. The report of this committee also contains a valuable series of references. The need for fuller quantitative data is emphasised and a number of suggestions are made for future work.

That certain forms of radiation may be harmful to the eyes is generally admitted, but the exact conditions that cause injury, and the amount of radiation that is harmful, have not been definitely ascertained.

Similarly, while it is common knowledge that habitual working in a poor light leads to eye strain and general fatigue, we have not at present comprehensive statistical data regarding

[1] See, for example, Dr S. Rideal on "The Relative Hygienic Values of Gas and Electricity," *Journal of the Royal San. Institute*, March 1908.

[2] "Affections of the Eye produced by Undue Exposure to Light," paper read at the Seventeenth International Medical Congress, held in London, August 1913.

[3] "Harmful Radiations and the Protection of the Eyes therefrom," *Trans. Illum. Eng. Soc. U.S.A.*, vol. ix., 1914, p. 307.

the amount of injury thus caused, simply because no sufficiently systematic and complete inquiry has yet been undertaken.

These are gaps in our knowledge that one would like to see filled before long.

Conclusion.

We may conclude this chapter by a few general remarks on the value of light, not only in connection with the eye, but as a means of preserving general health. Medical science now seems to recognise that abundant illumination is a necessity in the same way as pure water, fresh air, and proper sanitation. This view of the subject was strikingly expressed in an address delivered by Sir James Crichton-Browne about ten years ago.

"Sunlight," he said, "penetrates much deeper than the skin. It quickens the circulation, it increases the oxidation in the body, it enriches the blood, it promotes nutrition in every organ and tissue. . . . Fresh air, pure water, good drainage, unadulterated food, well-ventilated dwellings are cardinal sanitary requirements, and bright light must henceforth be added to their number."[1]

In addition, the effect of poor lighting, whether natural or artificial, reacts on the health in other ways. It leads to neglect of cleanliness, for what is not clearly seen will not be thoroughly cleansed. It increases the difficulty of processes which tax the eyes, and adds to the strain of arduous employment. It is specially objectionable in the case of trades which involve the handling of poisonous materials, and is favourable to the development of many diseases, such as tuberculosis and anthrax. Even normal healthy persons are notoriously apt to be depressed by working for long spells of time in gloomy, sombre surroundings. They become morose and their health eventually suffers. In the treatment in the best modern sanatoria great stress is laid on the value of abundant sunlight.

We may crystallise this general recognition of the hygienic value of good illumination by quoting the Italian proverb, "Dove non va il sole va il medico" ("Where the sun does not enter the doctor comes").

[1] "Light and Sanitation," address delivered before the Manchester and Salford Sanitary Association, 24th April 1902.

CHAPTER VI.

COLOUR AND THE EYE.

Some Theories of Vision and Colour Perception—The Eye compared with a Wireless Telegraphy Receiver—The Young, Helmholtz, and Hering Theories—Presumed Action of Rods and Cones—Colour-blindness—Edridge Green Theory—Evolution of Colour Sense in Man—Luminous Efficiency and Radiation—Incandescence, Luminescence, and Phosphorescence—Sensitiveness of Eye at High and Low Illuminations—Appearance of Coloured Objects by Artificial Light—Optical Resonance—Colours of Artificial Illuminants—"Artificial Daylight"—The Moore White Light—Practical Applications of Coloured Light—Colour in Interior Lighting—Decorative Effects.

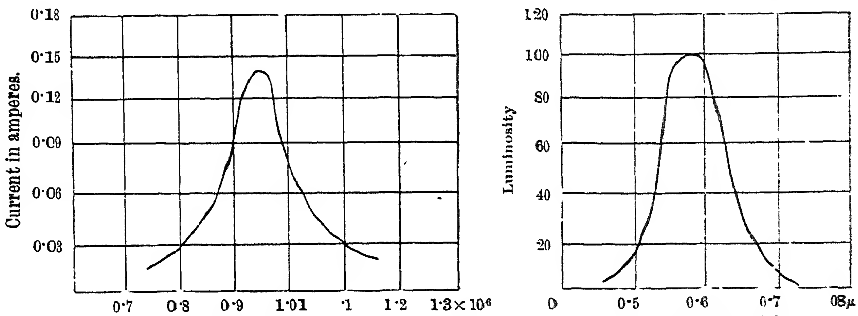
In the last chapter we have seen how, in determining the amount of light required for various purposes, we are driven to consider the peculiarities of the eye. In dealing with the question of colour we find exactly the same thing. There are always two distinct aspects, the physical and the physiological, from which each problem must be studied, and it may therefore be well to say a little more on the theory of colour perception.

The authors would like to make it clear that they do not profess to be in a position to present a theory which can be regarded as entirely satisfactory. This is a matter for the expert in physiological optics to determine. The older theories, such as those of Hering and Helmholtz, require substantial modification to account for many phenomena now known to us. So much is clear. But there are many points in connection with colour-vision which are still obscure, and on which even the greatest authorities seem to differ.

Some Theories of Vision and Colour Perception.

The exact manner in which the sensations of light and colour arise has long been a matter for speculation. We have seen that the origin of the stimulus seems to lie in the complex and delicate mechanism of the retina, and to be connected with the light-sensitive pigment thereon known as the visual purple.

Naturally, therefore, many physiologists and physicists have been disposed to explain the perception of light on a photochemical basis. Sir William Abney has expressed his belief to this effect, and the researches of J. Chunder Bose[1] have shown how readily many phenomena characteristic of the eye, such as its response to stimulation and its susceptibility to fatigue, can be reproduced with photoelectric silver cells. It appears to be generally believed too that the stimulation of the optic nerve system is accomplished by means of a minute electric current flowing from the retina, and this has been measured and found to be dependent on the intensity of the light striking the eye. It also appears to be greatest in the case of the yellow-green



(*a*) Wireless electrical receiver. (*b*) Human eye.

FIG. 68.—Comparison of the resonance curve of wireless telegraphy receiver with the luminosity curve of the human eye.

rays in the spectrum, to which, as we shall see shortly, the eye is most sensitive.

On the other hand, the light-receiving apparatus of the eye has been likened to the tuned receivers of electro-magnetic waves used in wireless telegraphy. Light-waves are merely electro-magnetic waves of very high frequency, and it is natural to suppose that they would be detected by somewhat similar means. To illustrate this point we reproduce an interesting curve, published not long ago by Dr Fleming,[2] connecting the frequency of the received electrical oscillation with the resultant current flowing through the receiving apparatus. By the side of this we reproduce the corresponding curve for the luminosity of the

[1] J. Chunder Bose, "Response in the Living and Non-living"; see also "An Electrical Theory of Vision," by same author, *Photographic Journal*, 1902, p. 146.

[2] *Electrician*, 31st May 1907.

spectrum as seen by the eye, and it will at once be seen how strikingly these curves resemble each other. Sir Oliver Lodge has likewise compared the mechanism of the eye with the coherer used in the receiving circuit of a wireless installation. He imagines that an E.M.F. is always present in the eye ready to produce an electrical current, which in turn may be supposed to give rise to the sensation of light. He also suggests that the optical coherer may be shaken by a muscular effort as soon as the light stimulus is removed, so that it returns to its former non-conducting state. According to this view there is always present in the eye a source of light-sensation. The light only 'pulls the trigger.'"[1]

It is interesting to observe that these two theories may prove to be merely different methods of expressing the same thing. For it is now believed that photochemical action takes place when the ions of the chemical substance acted upon have a natural period of vibration comparable with that of the wave attacking them; consequently they move in sympathy with the wave, this oscillation results in the breaking up of the old molecules and the creation of new ones, and chemical action occurs.

This difficulty of being forced to imagine apparatus situated in the retina which has not yet been demonstrated to exist is encountered in most of the theories that have been put forward to explain the perception of colours. One of the most widely known theories of this kind (which has indeed taken such deep root in the existing text-books on the subject that any modifications in it almost pass unnoticed) is that upheld by Young, Helmholtz, and Maxwell. Having received such distinguished support, it is not unnatural that the theory should have been generally adopted, perhaps in a more unquestioning spirit than would have been approved by its original sponsors. According to this theory there are present in the eye three distinct elementary colour sensations, the red, green, and blue-violet, and the impression made by any mixed colour consists in the combined impressions of these three primary sensations. The Young theory seems to fit in with the wireless telegraphy analogy rather well. The idea appears to be that there may exist three distinct sets of organs responding, like the tuned receivers used in wireless telegraphy, to light waves of the frequencies corresponding to the three primary colours. No such receiver

[1] *Signalling through Space without Wires.*

can be tuned to respond only to waves of exactly one frequency. There will exist a wide range of frequency on either side of the point of maximum sensitiveness, for which a gradually diminishing response will be obtained (just as shown in fig. 68).

From the purely physical side the theory has much to recommend it. It has been demonstrated that by mixture of these three colours one can actually reproduce practically all the known tints, and advantage of this fact has been taken in the so-called "three-colour processes" used in lithographing and in colour-photography. It is therefore a convenient method of regarding colour-mixture. On the other hand, there are certain phenomena which suggest that the theory is not a complete statement of the facts. For example, it appears that the statement that *any* colour can be matched in this way is not rigidly true, and that the exact colour to be selected for the blue-violet is not certain; in some cases a genuine blue, in others a colour more closely approaching violet, is said to be necessary. Again, one essential consequence of the theory would appear to be that light and colour are inseparable. Yet it is known that even the normal eye loses at weak illuminations the power of distinguishing colours, while still able to see light; and it has been shown that this effect is connected with physiological peculiarities of the retina which have not been taken into account by the Young theory.

Like most theories of colour-vision, the Young theory finds itself in difficulties when applied to explain colour-blindness Such cases were formerly explained on the assumption that one of the three primary sensations was either weak or absent. Some people who habitually confused reds with black, for example, were termed "red-blind," others "green-blind," and so on. Some interesting experiments conducted by Prof. Burch seem to have been in good accord with this idea.[1] By focussing a strong coloured light on the retina, so as to fatigue that sensation, he produced temporary colour-blindness. For example, after the eye had been exposed to very powerful red light, red objects appeared dead black.

But it is evident that colour-blindness may be of a more complicated character, and many cases have occurred which appear to have been inexplicable on the basis of the Young theory alone.

For example, cases seem to be known in which the power of

[1] *Proc. Roy. Soc. of London*, 1898.

distinguishing colours is defective or even entirely absent, but yet there is no corresponding loss in the perception of light. Dr Edridge Green mentions the case of a certain sea-captain who suddenly lost his power of distinguishing colour almost completely.[1] Everything appeared a nonedescript drab hue, and the only tint that he could recognise at all was blue. Yet his ability to perceive light and shade did not seem to be impaired, and as a matter of fact, he continued to discharge his duties without difficulty. It would seem unreasonable to attempt to explain all cases of colour-blindness on a purely physical basis. For the visual apparatus receiving the light-wave, the nerves conveying the stimulus to the brain, and the perceptive centres in the brain itself, all play their part in enabling us to distinguish colour. A weakness anywhere in this chain of connection may produce abnormal vision. Thus, according to Edridge Green, concussion and congestion of the brain frequently cause colour-blindness, and this defect accompanies some forms of insanity. Various drugs also affect colour-vision, and santonin, for instance, is said to produce "yellow vision" in bright light and "violet vision" in weak light. From the purely physiological side it seems difficult to find much support for the Young theory, for no vestige of the three sets of organs gifted with the powers of perceiving respectively red, green, or blue light has yet been observed.

There are certain other colour phenomena which led physiologists at one time to adopt another theory of vision. It has been mentioned that at very weak illuminations the eye loses its power of distinguishing colours. Bright red shades become jet black, greens and blues appear a peculiar white. It is also stated that in very intense light there is confusion of colours, due to dazzle. These facts, coupled with the knowledge that forms of colour-blindness exist in which destruction of the colour-sense does not involve loss of perception of light, led to the so-called Hering theory. According to this theory there exist three photochemical substances in the eye. The first of these is supposed to undergo a certain constructive change in one direction when acted upon by red, and the opposite destructive change when subjected to green light. The second element undergoes similar changes for yellow and its complementary colour blue, while the third element is supposed to be responsible for the sensations of light only, and to undergo similar chemical

[1] *Colour-blindness and Colour Perception.*

changes corresponding with black and white. It will be seen therefore that the theory permits of a light-sense as distinct from a colour-sense, and is compatible with the phenomena at very weak and very strong illuminations mentioned above.

These three processes, it was supposed, might be accomplished by the chemical changes in three distinct photochemical pigments in the retina. It is true that these substances, like the three sets of organs presupposed by the Young theory, have not yet been detected physiologically, and are purely supposititious. But assuming their presence, the theory suggested a plausible method of accounting for certain effects known as successive and simultaneous contrast.

Other theories of colour-vision have been put forward, and interesting discussions of some of these will be found in Helmholtz's great book on physiological optics.

It may be well at this stage to give a brief account of some of the speculations that have been made regarding the behaviour of the minute retinal elements known as the rods and cones. The theory of the action of these organs is generally attributed to v. Kries.[1] It has attracted much interest, and has been regarded as throwing light on a number of circumstances which neither the Young nor the Hering theory seems competent to explain. The theory of the action of the rods and cones has been applied by Lummer[2] and others to account for phenomena observed in heterochromatic photometry.

Allusion has already been made to the curious changes in the brightness of colours that occur in fading illumination. Suppose that two pieces of bright red and green paper, about 6 inches square, are pasted up side by side and so chosen that, with the eye at a distance of about 10 inches, they appear equally bright. Then it will be observed that if the eye is removed to a distance of 40 feet or so the brightness in the two cases is no longer the same. The red appears unquestionably the brighter of the two. This phenomena is sometimes spoken of as the "yellow spot effect."

Now, suppose that we return to our position close to the coloured papers and try the effect of gradually reducing the illumination (if the room is lighted by daylight this can conveniently be done by gradually pulling down the blinds). It will soon be

[1] "Über die Funktion der Netzhautstäbchen," *Zeitschr. f. Psych. u. Phys. d. Sinnesorgane*, vol. ix. pp. 81–123, 1894.

[2] *Die Ziele der Leuchtechnik*, 1903.

seen that the green is the brighter of the two. As the illumination is weakened still further the colours become indistinct, and eventually the red appears jet black and the green appears a ghostly white. (As mentioned in the last chapter, Prof. Burch has found that after waiting for some hours in complete darkness the power of distinguishing colours returns.)

Now neither the Young theory nor the Hering theory could explain why this should be the case. There is another fact for which neither theory can account, namely, that when the surfaces subtend a very small angle at the eye the Purkinje effect (as the above phenomena is termed) does not take place. Both colours fade away together into darkness.

The theory of the rods and cones has been briefly alluded to in the last chapter. At one time it seemed that this theory explained completely the various difficulties met with in colour photometry and it is still quoted to a great extent by photometric experts. But it is only right to mention that the very latest investigations seem to show that it requires some modification. Nevertheless, this whole discussion is so interesting as an illustration of the bearing of physiological optics on photometry and judgment of colour that it cannot be passed by.

The essential points in the theory are as follows: The rods are believed to be sensitive to light, but not to colour. Light of any colour appears to them white, but they are most sensitive to blue-green light. They are, moreover, sensitive to very weak light, but as the illumination is increased they become, as it were, saturated and do not respond any further.

The cones, on the other hand, perceive colour, but are most sensitive to yellow light, and, while they do not respond at the low illuminations at which the rods can act, they continue to respond to increased stimulus, once they have started, long after the rods have ceased to do so.

Consequently, at very low illuminations, the rods are predominant Faint green and blue objects appear a luminous white, while red objects appear dead black. As the illumination is increased the cones suddenly begin to act and the colours appear. Then takes place what Lummer has aptly described as "the battle of the rods and cones." It is while this battle is in progress that the Purkinje effect is noticeable

But the Purkinje effect is believed to be complicated by the peculiar distribution of rods and cones over the retina. Outside the yellow spot the rods are most numerous, and there are only

isolated cones here and there; while at the extreme periphery only rods exist. Within the yellow spot, on the other hand, the cones are predominant, and there are relatively few rods; while at the very centre, the *fovea centralis*, there appear to be *only* cones and no rods at all. Consequently, when the luminous image falls within the yellow spot, little or no "battle of the rods and cones" takes place. Evidently this unequal distribution of the rods and cones might also explain how it is that the relative brightness of a red and green surface depends so greatly on the part of the retina on which the image is received. With a high illumination, such that the cones have presumably become the predominant organs, the effect is naturally less noticeable. It becomes pronounced for illuminations under about one-tenth of a foot-candle.

Another apparent consequence of the distribution of these retinal organs is that at normal high illuminations the centre of the eye possesses the greatest acuteness of vision. But in a very faint light this cone-supplied region is almost blind, and vision is accomplished mainly by the surrounding region. There are also people who are "day-blind," *i.e.* who can see as well as anyone in a dim light and in the night-time, but during the day possess less than normal acuity; such cases were assumed to be due to defective cone-vision. Other people have the characteristics of "night-blindness." They can see perfectly well in the daytime, but find it difficult to see their way about in the twilight, and were therefore supposed to have imperfect rod-vision. Other evidence in favour of this theory is based on the examination of the eyes of various animals. Birds in general retire to rest in the night-time. Indeed, their period of sleeping is so much affected by the intensity of light that they have been known to retire during a solar eclipse, and in some cases the sleeping hours of tropical birds in a menagerie have been controlled by the use of artificial light. Now, it is stated that the eyes of birds contain almost entirely cones and few rods. The retinæ of nocturnal creatures, on the other hand, such as the owl, the mole, and the bat, are said to contain rods only.

The above is an outline of the rod and cone theory. When the visual purple was discovered in the retina it was at first thought that the nature of vision was made clear, until it appeared that in the yellow spot, where acuteness of vision is greatest, no visual purple exists. The theory of the rods and

cones therefore seemed destined to replace theories depending solely on the action of the visual purple.

More recently, however, there appears to be a reversion to the older idea. Dr Edridge Green has announced that visual purple can be seen [1] in between the cones on the yellow spot, and that the swirling motions accompanying its motion outwards to the rods and inwards towards the cones can be demonstrated by various entoptic experiments.[2] This authority holds the view that vision is accomplished by the agency of the cones, and that the rods have only a secondary function of distributing the visual purple. To the ebb and flow of this substance, according as the eye is more or less dark-adapted, are due the curious phenomena which take place with fading illumination.

There also seems reason to suppose that the Purkinje effect can be accounted for to some extent without assuming any struggle for supremacy between two sets of organs to take place. For it appears that the low sensitiveness to red light, and the comparative high sensitiveness to the blue and green rays with weak stimuli, is characteristic of photochemical action in general. It is interesting to note that a similar effect has been noticed in the case of selenium cells.[3]

According to this view, the most essential element in colour-vision is the visual purple, the chemical changes in which stimulate the cones, which in turn transmit the message to the brain. It is pointed out that the complexities of colour-vision might partly be explained on the assumption that the visual purple contained quite a number of different photochemical substances, all having their characteristic range of sensitiveness to light of different colours.

Dr Edridge Green has also formulated a theory of colour-blindness. It is, of course, recognised that such defects may arise through injury to the retinal apparatus. In tobacco-blindness, for example, the colour-sense is frequently lost over small regions of the retina, so that the tints of large objects can be distinguished, while those of small ones are less readily perceived.

But it is also emphasised that in many cases the defect lies in the power of analysis in the brain. People are occasionally met with who are quite tune-deaf, not because their ears are defective, but merely because their power of analysing musical sounds has

[1] See *Illum. Eng.*, London, vol. ii., 1909, p. 210.
[2] *Jour. of Physiology*, vol. xli.
[3] A. Pfund, *Physical Review*, vol. xxxiv., May 1912.

never been properly developed. The same applies in some measure to colour. It would seem that even people with so-called normal vision do not properly discriminate the seven distinct colours said to exist in the spectrum; only the gifted few can really detect three distinct colours in the blue-indigo-violet region. Others there are who can apparently only distinguish five, four, three, two, or even one colour in the spectrum. This incapacity does not necessarily imply any loss in the perception of brightness, but only imperfect power of analysis.

The date at which the colour-sense in man first made its appearance seems very uncertain. Some writers, of whom Mr Gladstone was an eminent example, have put forward the view that colour-vision as we now know it has only developed within quite historic times. The evidence in favour of this view is largely philological, being based on the methods of describing colour found in such writings as those of the Hebrew prophets and of the ancient Greeks. For instance, the fact that Homer described the sea as "wine-coloured" has been adduced as evidence that he lived in an age when the sensation of blue was imperfectly developed. It is also said that the ancient Egyptians frequently confused the terms used for yellow and blue, and that the colouring adopted in their decorative designs for natural objects is such as to suggest defective colour-vision. According to the theory of evolution, it is difficult to understand how so radical a change could occur within such a comparatively short time, and it is therefore necessary to suppose that the colour-sense is a matter of education rather than evolutionary development. Grant Allen has collected interesting data relating to the colour-sense of many different living races.[1] He found that all, even the most degraded species, the bushmen of Australia and the wretched inhabitants of the Andaman Islands, appeared to have a well-defined sense of colour. He was therefore led to the conclusion that any such change in colour-vision must have come about very early in the prehistoric existence of mankind, and not in comparatively recent times.

The theory that colour-sense is mainly a matter of education seems, however, to fit in with Dr Edridge Green's experiences. It may be imagined that at one period all colours appeared the same, so that the spectrum would appear a uniform drab tint. The first step would be the development of a trace of red and violet at each end of the spectrum, merging in the centre.

[1] *The Colour Sense.*

Presently an intermediate colour in the centre might appear, and the other intermediate tints would make their appearance as the scale of perception improved. According to this view, cases of arrested development (people who can see only three, two, or even only one unit) are still met with, while people who can see only five colours are comparatively common. People who can see seven colours, on the other hand, are very rare. Dr Edridge Green contends that many perplexing cases which could not possibly be explained as being "red-blind" or "green-blind," etc., readily fall into place in this classification.

It is, however, necessary to make one other supposition. Besides inability to distinguish colour, we sometimes meet people with a somewhat restricted range of sensibility to light. This takes the form of shortening of the spectrum at one end. A person, for example, may find no difficulty in distinguishing red as a colour, but yet his eyes may be insensitive to very deep red light. When this condition coexists with imperfect colour discrimination the case becomes more complicated, and special methods of testing are needful. There may also be present subsidiary defects (such as tobacco-blindness, which only affects a portion of the retina), so that the diagnosis of colour-blindness calls for skill of a high order.

Enough has been said to show that the perception of light and colour is a complicated process which is far from being thoroughly understood as yet. Radical differences of opinion still exist, and the conclusions of authorities are constantly undergoing revision. We have entered into this subject in some detail because it illustrates so strikingly the need for co-operation between the physicist and the physiologist. It also affords a glimpse into the complexities of vision which underlie many of the problems awaiting the illuminating engineer.

Luminous Efficiency and Radiation.

The bearing of such facts as those discussed above at once becomes apparent when we turn to the problem of the production of light. Here we find the twin aspects of the subject —the physical and the physiological—in sharp relief. We must study closely the physical processes involved in the production of light (whether by incandescence, luminescence, or other means), and we have likewise to trace the effect of the light produced on the eye and to ascertain what varieties

of radiation are most efficient for the purpose of "creating brightness."

A résumé of some of the latest recent investigations in this direction was given by one of the authors in a recent number of *Science Progress*.[1] For everyday purposes we might perhaps assume that the ideal source of light should (1) develop all its energy in a visible form, and (2) that this energy should be so distributed throughout the spectrum that its light should be approximately of a "white" character. (The exact meaning to be attached to the term "white" is a little vague. It would comprise a spectrum which was continuous and not widely different from daylight.)

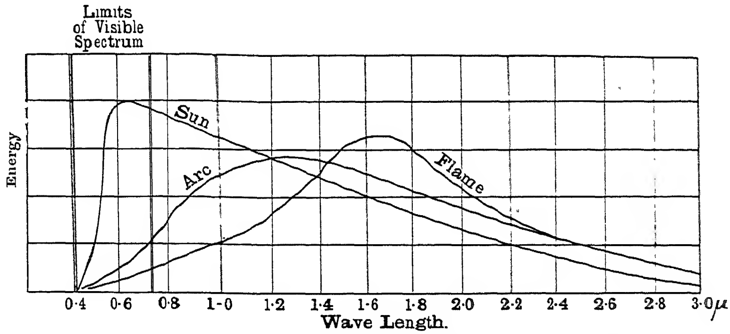


FIG. 69.—Distribution of energy in the spectrum of the sun, arc, and flame (Langley).

Most illuminants produce a vast amount of energy which is non-visible and therefore of little service to the illuminating engineer. Many researches have been made with a view to determining the percentage of energy developed in a useful form. Into the nature of the apparatus used for such researches we cannot enter deeply. Readers may be referred to a series of articles by Drysdale[2] and Coblentz[3] on this subject. The results of such investigations are not entirely harmonious, being affected by certain experimental difficulties, and also to some extent by the definitions of "radiant efficiency" or "luminous efficiency" assumed. Most of these researches involve the exploration of the spectrum with a bolometer or thermopile so

[1] "The Luminous Efficiency of Illuminants," April 1912, p. 536.

[2] "The Production and Utilisation of Light," *Illum. Eng.*, London, vol. i., 1908.

[3] "The Distribution of Energy in the Spectra of Illuminants," *Illum. Eng.*, London, vol. iii., 1910.

as to estimate the distribution of energy in the visible and non-visible regions.

The one broad fact which stands out from all such researches is the surprisingly small percentage of the total energy which is available as light. As an illustration, we may take the following table compiled by Lux.[1] It will be noticed that in most cases all but about 5 per cent. or less of the energy supplied is wasted. In order to illustrate these relations more precisely we reproduce in fig. 69 the distribution of energy in the spectra of various illuminants, and in fig. 70 the curve of luminosity of the eye.

TABLE II.—LUMINOUS EFFICIENCY OF VARIOUS ILLUMINANTS (ACCORDING TO LUX).

Source.	Luminous Efficiency (percentage total energy radiated as visible light).
Petroleum lamp	0.25
Incandescent gas, upright	0·46
" " inverted	0·51
Electric incandescent lamp:	
Carbon filament	2·07
Tantalum "	4·87
Tungsten "	5·36
Arc lamp, d.c. enclosed	1·16
" " open	5.6
" " flame	13·2

It will be seen that the maxima of these curves are in general far out in the infra-red, so that the percentage of energy that falls within the visible range is exceedingly small. There are obviously two ways in which the yield of light might be improved. We might, firstly, try to shift the maximum of the curve backward until it came directly over the middle of the visible spectrum, like that of the sun. Or we might strive to produce light in such a way that the useless non-visible rays are omitted entirely.

Here again the complete discussion of the underlying physical problems of light-production would carry us too far afield. A good analysis of these conditions, followed by a very complete series of references to literature on the subject, has

[1] "The Efficiency of Common Sources of Light," *Illum. Eng.*, London, vol. i., 1908.

been recently published by Dr Hyde.[1] It may be mentioned, however, that most illuminants which owe their light to high temperature (such as an electric glow-lamp and a flat-flame gas-burner) broadly resemble the "black body" closely studied in the classic researches of Lummer and Pringsheim. Kirchoff has shown that a body is capable of emitting only the radiations which it absorbs; consequently, a truly black body absorbs and also emits all varieties of radiation. When heated, such bodies produce a confused series of vibrations of varying frequency, and, as the temperature of incandescence increases, the dominant frequency rises according to a well-defined law. Lummer and Pringsheim have traced out the radiation curves of the black body very fully. They have pointed out that the energy maximum is advanced towards the visible spectrum with increasing temperature, and this leads to a corresponding improvement in the percentage of energy radiated in a luminous form.[2] At the enormous temperature of the sun (see fig. 69) the maximum is actually immediately above the centre of the visible spectrum, and Dr Drysdale has calculated that under favourable conditions as much as 50 per cent. of the energy might then be available as light. It is most interesting to observe, in passing, that our vision has apparently been developed so as to make the best possible use of natural light. Presumably if the maximum of the energy curve of the sun had been located in the blue, our eyes would have been most sensitive to light of this description.

The researches of Lummer and Pringsheim serve to show the importance of increased temperature of incandescence. As the efficiency of our illuminants has improved, the energy maximum has travelled nearer the visible spectrum and the light has become appreciably whiter in tint. At the present moment it hardly seems practicable to increase the temperature sufficiently to bring the energy maximum actually within the visible region. But there is room for considerable progress in this direction. Our present limits are often set by purely practical considerations.

There is another possible means of improving the efficiency of illuminants, which has already proved very serviceable, namely, to choose materials which depart widely from the black-

[1] "Physical Characteristics of Luminous Sources," lecture delivered at the Johns Hopkins University, Baltimore, U.S.A., 1910.

[2] *Verh. Deutsch. Phys. Gesell.*, 1899, p. 214.

body law and exhibit "selective radiation." Substances which are highly polished—white, grey, or coloured—usually exhibit this quality. What is needed is a material which absorbs, and therefore emits visible light as completely as possible, but which acts as a highly reflecting substance towards the infra-red rays. The Nernst filament, the incandescent mantle, and the metallic-filament lamp all seem to exhibit this quality to some degree, and it is possible that great advances in this direction are before us.

It hardly seems likely that an incandescent solid could be made to yield the theoretically ideal luminous efficiency (*i.e.* to emit only visible rays and no others). Incandescent solids have, nevertheless, one considerable advantage; they produce a continuous spectrum, and therefore give fairly good colour definition.

There is still a little uncertainty as to what is meant by "white light." Most people would understand by this a light similar to that from the normal white sky. But assuming that we can specify the nature of white light sufficiently close for practical purposes, it is of interest to inquire what the ideal efficiency would be of a source which produced these particular rays in the required proportions *and no others*. According to P. G. Nutting,[1] whose determination at the Bureau of Standards has been made with special care, such a source would yield as much as 26 c.p. per watt. Seeing that the most efficient illuminants at present available probably does not yield more than 4 to 5 c.p. per watt, it is evident that we are still a long way from our ideal.

In what has been said above it has been assumed that our ideal illuminant should not only emit all the visible rays in the spectrum, but should do so in the proportions which constitute daylight. Yet it is clear that by disregarding colour, and aiming only at the production of as bright a light as possible, considerably more efficient results might be obtained. It is obviously uneconomical to include the rays at the extreme ends of the spectrum, the deep red and violet, which are just on the borderland of visibility. Clearly, if quantity of light be the sole consideration, our right course would be to ascertain the precise ray for which the sensitiveness of the eye was a maximum, and then produce only this variety of radiation.

The question arises, therefore, where in the spectrum this

[1] *Bull. Bureau of Standards*, 15th May 1911.

position occurs. At once we find ourselves faced by the physiological peculiarities of the eye described in the first portion of this chapter. The answer depends on the intensity of the light. We have seen that at very weak illuminations the eye is apparently highly sensitive to the blue-green end of the spectrum, but comparatively insensitive to red. As Sir Wm. Abney and many other investigators have shown, the maximum (sunlight) luminosity for high illuminations commonly occurs near 0·58μ; whilst for a fully dark-adapted eye and a very faint illumination it may occur near 0·53μ, or even lower. This effect is illustrated in fig. 70.

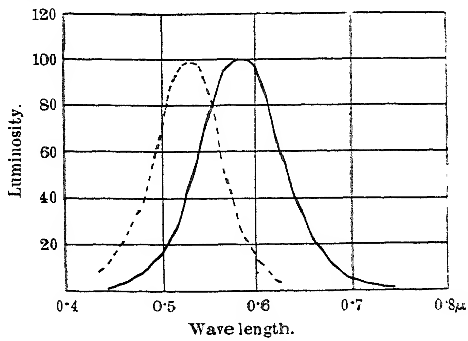


FIG. 70.—Showing distribution of luminosity in the solar spectrum at high illuminations (curve drawn full) and by a very feeble light (curve dotted).

It is evident, therefore, that the most efficient form of light will depend on the use to which it is put. For example, yellow monochromatic light might be the best for a very brightly lighted advertising placard. But for marine signals, the value of which is judged mainly by the limiting distance at which the light can just be seen as a luminous point, greenish blue light might be preferable.

The great majority of industrial uses of light demand a fairly high illumination, and should be judged on what may be called the "upper register" of vision. On this assumption Nutting has calculated that the most efficient light for creating brightness is the yellow-green (0·54μ). He estimates that if it were possible to secure a source which produced only this quality of radiation, an efficiency as high as 65 c.p. per watt should be attained.

This principle of "luminescence," *i.e.* the production of certain lines in the spectrum corresponding with the natural frequency of oscillation of a substance, has been used to some extent in practice. In the flame arc a certain amount of light is derived from the incandescent tips of the carbons, but the greater part of it comes from the luminous bridge of vapour between the electrodes. The high efficiency of the yellow-flame arc seems to be due to the fact that materials yielding several vivid

lines in the yellow-green and orange are present in this stream of vapour. These lines are superimposed on the continuous spectrum due to the incandescent carbon, and naturally distort the colour of objects illuminated by them to some extent.

The judicious use of the luminescence set up in rarefied gases or metallic vapours should yield efficiencies considerably in excess of those attainable by the use of incandescent solids, which yield a jumble of vibrations, many of them non-luminous. But, naturally, the production of line spectra is apt to occasion some degree of colour distortion. A notable instance is the mercury-vapour lamp, which, as we have seen, yields only strong lines in the yellow, green, and blue-violet, but no red.

Inventors have long cherished the fascinating idea of a cold phosphorescent light which, portable and self-contained, would absorb light by day and return it automatically when night has fallen. Fanciful as such an idea may seem at the moment, it is not inconceivable that it may be realised in the future. At present, it is true, phosphorescent materials yield but a feeble light of short duration, and its colour is usually a peculiar green or blue, hardly suitable for practical illumination. Nevertheless, progress has been made. Our stock of phosphorescent materials has improved, and we understand better how to prepare such substances in a highly active condition. Moreover, we have now available sources like the quartz tube mercury-vapour lamp, which are very rich in the ultra-violet rays; on the exciting action of these rays the phenomena of fluorescence and phosphorescence mainly depend. By the aid of such lamps wonderful results have been obtained in America, and were witnessed by one of the writers in the course of a recent visit to that country, but little has yet been published on the subject. For novel stage effects their value is already recognised. Mechanical butterflies may be coated with luminous paint, and by the same means the dress of a danseuse can be made to gleam with living fire. It has even been found possible to produce in the laboratory landscapes glowing with approximately natural colours.

The possibilities of phosphorescence appeal to the lighting engineer for another reason. There seems good reason to suppose that the luminous efficiency of such a method of illumination would be exceedingly high. Prof. S. P. Langley[1] many years ago came to the conclusion that all the recognisable radiation from the fire-fly was concentrated in the visible spectrum—

[1] Langley and Very, *American Jour. of Science*, xl. p. 97, 1890.

a result which seems to have been substantially corroborated by the later researches of Ives and Coblentz.[1] Dr E. L. Nichols of Cornell University has also made researches on a large number of phosphorescent materials; he, too, has been struck by the high luminous efficiency of such sources.[2]

The Colour of Illuminants and "Artificial Daylight."

Let us now consider further the question of colour in illuminants. We have at present no exact standard of what constitutes "white light." Most people apply this term somewhat loosely to the colour of daylight, on which our impressions of the colours of objects mainly depend. When very accurate colour-matching is essential, work is preferably, and sometimes necessarily, carried out by daylight. Even this is not always quite enough; it becomes necessary to reject results obtained on days when the atmospheric conditions are peculiar and the light abnormal. "Daylight" is itself variable both in quality and intensity. The colours of "diffused daylight" (*i.e.* light from the white sky), direct sunlight, and light from the blue sky are, as Dr Nichols has shown, by no means identical. Even diffused daylight, which is generally regarded as the best natural white light, differs according to the locality, and it is a well-known fact that in towns where foggy and smoky conditions prevail, the quality of the light is distinctly redder than in the country. The influence of altitude is strikingly shown in fig. 71. This is taken from the researches of Prof. Langley, who determined the distribution of energy in the solar spectrum at the base and the summit of Mt. Whitney, one of the loftiest peaks in the Sierra Nevada, 15,000 feet high.[3] This illustrates very

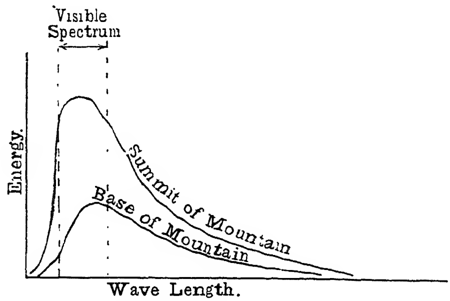


FIG. 71.—Distribution of energy in the solar spectrum at the base and at the summit of Mt. Whitney, Sierra Nevada, 15,000 feet high (Langley).

1 *Trans. Am. Illum. Eng. Soc.*, Sept. 1909.

2 Paper read before the Franklin Institute, 29th March 1906; *Illum. Eng.*, U.S.A., Oct. 1906.

3 Lecture before the Royal Institution, 1885, London.

strikingly the absorption of the blue and ultra-violet. Could we but penetrate above the earth's atmosphere altogether, the colour of sunlight would presumably appear a rich blue.

Fig. 72 represents the conclusions of Dr Nichols on the selective atmospheric absorption of various colours by the atmosphere.

It will be seen, therefore, that for accurate colour work an artificial illuminant giving light of exactly the same colour as normal daylight, but more constant in operation, would be very useful. It may perhaps be thought that the variations in colour of daylight are not very serious, and except in very accurate work this is perhaps so. But the fluctuations in intensity also constitute a difficulty. In the short winter days the hours of work are necessarily curtailed, and even in the summer time interruptions may be caused by the abrupt diminution in brightness due to sudden storms, clouds, or fog.

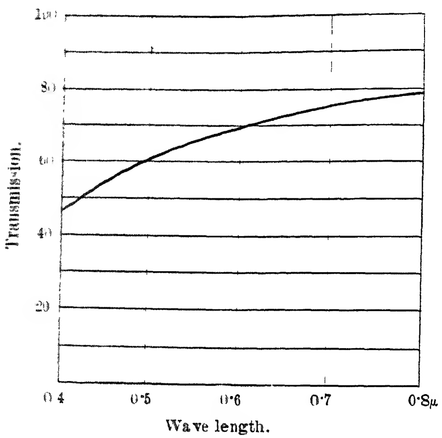


FIG. 72.—Transmission of light of various colours by the earth's atmosphere (Nichols).

The colours of artificial illuminants in general differ considerably from that of daylight. Even leaving out of account such illuminants as the mercury-vapour lamp and the neon tube, which yield very peculiar line spectra, there is plenty of variation. So long as we are concerned with the appearance of white objects, which reflect all the colours of the spectrum equally well, the variations in such sources as the incandescent mantle and the electric carbon and metallic filament do not greatly trouble us. We soon become accustomed to their colour and accept a white object illuminated by their rays *as* white. It is, indeed, questionable whether for ordinary everyday purposes people desire an exact duplicate of daylight. Such a light gives the impression of being somewhat "cold," and there does seem a preference for mellow yellow rays, which give a suggestion of warmth and comfort. As explained in the previous chapter, this

may be due to mental association. On the other hand, we must bear in mind that the mere fact of the whiter light being a novelty may cause a prejudice against it. People now seem to be getting accustomed to the light of the tungsten electric lamps, the light of which appeared cold at first. Looking backward, we find exactly the same impressions regarding the gas flame, nowadays regarded as giving a comparatively warm tint. Thus in 1819 the great chemist Clement Desormes spoke of the new illuminant, gas, as follows:—[1]

> "The light is of a disagreeable yellow colour, entirely different from the red and warm gleam of oil lamps; it is of dazzling brightness; its distribution will be impossible and irregular, and it will be much dearer than oil lighting. . . ."

Yet when the electric arc lamp appeared in 1874, we find another writer extolling the warm hues of the old gas-burner.

Thus Mons. J. Baille:—[2]

> "La nuance de la lumière électrique est triste, les objets se teignent d'une couleur livide et blafarde due à l'apparance bleuâtre des rayons et il n'y a même pas à desirer que cette lueur remplace les becs de gaz qui égayent et font vivre les boulevards. . . ."

However, setting aside the question whether or no it is desirable to imitate daylight for general purposes of illumination, it is obvious that the variation in tint of artificial illuminants gives rise to inconvenience when we are at all concerned with the observation of colours. Besides certain industries which demand great accuracy in this respect, such as dyeing, colour-printing, textile work, etc., there are many other cases in which confusion of colour is a drawback. For example, the fact that flowers, dresses, carpets, wall-papers, etc., which are selected by daylight may appear quite a different hue under artificial light is a difficulty. In a draper's shop it is by no means uncommon to see the shopkeeper carry the material to the doorway in order to let a customer judge of its true colour. Many colours which match under artificial light may not do so in the daytime, and *vice versa*. At present the artist's work must be done in the daytime, and pictures illuminated by gas or electric light rarely exhibit exactly their true colours. An exact artificial daylight might enable such work to be done in the evening, and might

[1] See Cantor Lecture before the Royal Society of Arts, London, by Prof. Grylls Adams, 1881, "on Scientific Principles of Electric Lighting."

[2] Eugène Defrance, *Histoire de l'Éclairage des Rues de Paris*, p. 187.

also prove acceptable for the artificial illumination of picture galleries. Among other industries which demand white light may be mentioned the grading of hops, flour, coffee, and tobacco (which is sometimes done by colour), and the examination of precious stones.

The apparent hue of an object depends mainly on two things, (1) its intrinsic capacity for reflecting various colours, and (2) the colour of the light by which it is illuminated. To these might perhaps be added certain physiological factors, such as the state of adaptation of the eye, the personal colour-vision of the observer, and the effect of simultaneous contrast from adjacent colours. From a practical standpoint these last three items are not of very great importance as a rule, although in special circumstances they may become so. But it goes without saying that a trained expert in colour-matching will often recognise slight variations in colour which are not detected by the ordinary observer.

The discussion of the physical explanation of the colours of surfaces would take us too far afield. A distinction has to be drawn between the colours of polished surfaces and thin films, which are often determined by interference and diffraction of light: and the colours of matt surfaces. In the former case the colour may be determined by what takes place at the extreme outer surface of the material, in the latter it may be due to the fact that the light has penetrated the upper layer of the material and then been reflected out again, losing some of its constituent wave-lengths while doing so.

In passing, it is of interest to mention the theory of "optical resonance." According to this theory the colour of a surface may be due to the fact that it contains minute particles whose size enable them to resonate with certain wave-lengths of light. It is suggested that the comparatively large particles would vibrate in sympathy with the less rapid light-waves and thus emit red light, the smaller particles would respond to the green and blue end of the spectrum, while still smaller ones would be unable to reflect visible light at all, but might respond to ultra-violet rays. Most surfaces contain particles of all sizes and reflect mixed light, but by restricting them to certain limits approximately monochromatic light would be obtained. In confirmation of this it may be recalled that in photographic processes the colour of the print can be varied within wide limits, according to the rate at which deposition occurs and the

size of the grains of material left upon the paper. Chemists recognise a similar effect in the formation of fine precipitates and emulsions.

Among the most interesting researches on this subject are those of Kossonogoff. By means of a very perfect microscope he was able to recognise as separate particles the minute grains of colouring matter on the wing of a butterfly.[1] It appeared that the diameter of these grains varied between the limits of the visible spectrum. The portion of the surface which gleamed with any particular colour was found to be composed of particles, each having a diameter almost exactly equal to the wave-length of the light reflected. Particles varying in diameter from $0 \cdot 4\mu$ (corresponding with violet) up to $0 \cdot 7\mu$ (corresponding with deep red) were detected, and there were also still smaller grains which appeared black. Coarser particles merely diffract and scatter the light in all directions without giving it any particular colour. Similar conclusions were reached by Prof. R. W. Wood [2] as a result of experiments on fine metallic films, and are likewise applicable to the colour of *transmitted* light.

Naturally an object cannot in general reflect rays which do not exist in the light illuminating it. For example, a deep red surface illuminated by the mercury-vapour lamp, which contains no red rays, appears black. There is thus a loss both in colour and in brightness. (An exception to this statement must be made in the case of fluorescence. There are certain substances which have the power of transforming the wave-length of some of the rays striking them. For example, the rhodamine reflector used with the mercury lamp actually converts some of the green and blue rays into red, and therefore appears pink and not black by the light of the lamp. But we find in practice that under ordinary circumstances fluorescence is either absent or too feeble to exert any appreciable effect.)

When, therefore, we have to deal with a line spectrum in which certain colours, or portions of a given range of colour, are entirely missing, the hues of objects illuminated are necessarily distorted. In the same way, if part of a continuous spectrum is accentuated, colour distortion will occur. The majority of artificial illuminants yielding continuous spectra differ from daylight mainly in having relatively less blue and more red in their composition. Consequently the green and blue shades are

[1] *Physikalische Zeitschrift*, 4, pp. 208, 257, 1902–3.

[2] *Phil. Mag.*, 1902, p. 396.

apt to appear unduly dark by artificial light, and are sometimes confused together; red and orange, on the other hand, may be unduly prominent.

There are several methods of comparing the colour values of artificial illuminants. Some of these are well illustrated by a paper read by Mr T. E. Ritchie before the Illuminating Engineering Society in 1911.[1] He arranged a series of coloured ribbons and illuminated them successively by the light of various lamps. Particulars were noted of the visual effect of the various colours, the change in hue being described verbally as set out in Table III.

Tests were also made of the reflecting power of each of the ribbons. If the reflecting power of each of these ribbons proved to have exactly the same value by daylight and artificial light there would be a strong presumption that the spectra of the illuminants were identical. But an exceptionally high coefficient for a certain colour would indicate that the illuminant was richer than daylight in these particular rays. Tests of the ribbons were also made with the tintometer. Finally, a series of photographs of the ribbons were taken with special Wratten plates, which, it is stated, are sensitive to the various colours of the spectrum in almost exactly the same manner as the eye. Here, again, the fact of the tones of the ribbons coming out in exactly the same way (under standard conditions as regards illumination and development) in the case of daylight and an artificial illuminant would be evidence of a close resemblance between their spectra.

During the last few years the idea has often been adopted of arranging a series of booths, each illuminated by a different form of lamp, in which the effect of various illuminants on coloured articles can be demonstrated. This gives a rough visual conception of the differences that can be produced in this way. Special instruments have also been devised to study the composition of colours numerically. The tintometer apparatus involves the matching of any prescribed tint by combinations of coloured glasses of varying opacity. In the Aron instrument[2] tints can be reproduced by a combination of polariser and analyser with a quartz plate of prescribed thickness in between. By this means it is stated a colour can be imitated with sufficient exactitude, and by reproducing the adjustments the colour can

[1] *Illum. Eng.*, London, Feb. 1912.

[2] "Das Chromoskop," *Elektrot. Zeitschr.*, 27th July 1911.

TABLE III.—CHANGES IN THE APPEARANCE OF COLOURED OBJECTS UNDER DIFFERENT LIGHTS (T. E. RITCHIE).

Description of Light used.	Appearance.	Colour.					
		Brown.	Red.	Green.	Mauve.	Blue.	Orange and Yellow.
Bright diffused daylight.	Bluish white or pure white.	Normal.	Normal.	Normal.	Normal.	Normal.	Normal.
Inverted "O.I." arc lamp.	Bluish white or pure white.	Normal.	Slightly brighter than normal.	Normal.	Slightly darker than normal.	Normal.	Normal.
Enclosed arc lamp.	Bluish white.	Darkened.	Lightened several shades.	Darkened considerably.	Darkened slightly.	Darkened slightly.	Darkened slightly.
Metallic-filament incandescent lamps.	Yellow white.	Lightened and changed to reddish tint.	Lightened many shades.	Darkened and changed to a yellower tint.	Changed to redder tint.	Darkened changed to purplish colour.	Brightened and changed to a more orange shade.
Inverted incandescent gas.	Greenish yellow.	Darkened.	Lightened many shades.	Darkened and changed to a yellower tint.	Darkened and changed to a redder tint.	Darkened and changed to a more navy blue.	Brightened many shades.
Carbon-filament incandescent lamps.	Orange yellow.	Reddened in tint.	Lightened many shades.	Darkened and changed to a yellower tint.	Darkened and changed to a pinker tint.	Darkened and changed to a much more purple colour.	Brightened and changed to a deep orange.
Ordinary gas light.	Yellow	Reddened in tint.	Lightened considerably.	Changed to a yellower green.	Changed to a pink rose-coloured tint.	Darkened and changed to a more navy blue.	Brightened and changed to orange.
White flame arc lamp.	Bluish white.	Slightly reddened in tint.	Lightened many shades.	Changed to a yellower tint and lightened slightly.	Changed to a bluer and darker shade.	Brightened and changed to a more intense blue.	Changed to a deeper and more orange colour.
Yellow flame arc lamp.	Deep yellow.	Darkened slightly.	Changed to a brick red.	Deadened and changed to a yellower colour.	Darkened considerably and changed to a purple.	Darkened and changed to a more navy blue.	Changed to a deeper and more orange colour.
Mercury-vapour lamp.	Pale blue-green.	Changed to a greenish colour.	Changed to almost black.	Lightened considerably.	Changed to a slate-blue grey.	Deadened.	Changed to a greenish yellow.

always be repeated. It is to be noted, however, that the scale of colour values is essentially arbitrary.

Dr H. E. Ives[1] has devised a form of "colorimeter" in which three colours—red, green, and blue—can be blended by persistence of vision and in any desired proportions. The numerical proportions of the constituents seem to represent more closely the actual colour constitution on the surface viewed, but it may perhaps be doubted whether the method is exactly applicable to line spectra or even to continuous spectra which have peculiar "peaks." Perhaps the best method of judging the resemblance of an illuminant to daylight is to compare the spectra, colour by colour, right through the visible range. Many elaborate forms of apparatus have been designed for the purpose.[2] If the ratio between the intensities at every point in the spectra was unity throughout the entire spectrum, one would surely be justified in

TABLE IV.—INTENSITIES THROUGHOUT THE SPECTRUM OF VARIOUS ILLUMINANTS (NICHOLS).

	Violet.		Blue.	Green.		Yellow.	Orange.		Red.
Wave-length, μ	0·35	0·4	0·45	0·5	0·55	0·59	0·6	0·65	0·7
Illuminant:									
Average daylight	1·00*	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
Arc light . .	0·36*	0·45†	0·6	0·69	0·91	1·00	1·04	1·15	1·20
Acetylene .	0·35*	0·35	0·45	0·60	0·78	1·00	1·05	1·38	1·85
Oil lamp . .	0·10*	0·15	0·25	0·40	0·70	1·00	1·12	1·84	2·8
Gas flame .	...	0·25	0·33	0·50	0·80	1·00	1·10	1·60	2·5
Incandescent mantle:									
Old (1894) .	...	0·55	0·7	0·92	0·97	1·00	1·10	1·22	0·9*
New (1908) .	...	0·28	0·45	0·64	0 84	1·00	1·03	1·16	1·4
Electric incandescent:—									
Carbon filament	...	0·26	0·40	0·58	0·77	1·00	1·08	1·38	1·92
Nernst „	...	0·18	0·30	0·50	0·74	1·00	1 05	1·35	1·7
Tantalum „	...		0·28	0·49	0·74	1·00	1·08	1·38	1·8
Tungsten „	...	0 30*	0·42	0·60	0·80	1·00	1·04	1·30	1·6

* Estimated.

† A strong blue line occurred in spectrum near this point, giving a ratio of about 3·55.

[1] *Trans. Illum. Eng. Soc. U.S.A.*, Nov. 1908.

[2] See, for example, Vierordt, *Pogg. Ann.*, cxxxvii. p. 200; Glan, *Wied. Annalen*, 1877; Draper, *Phil. Mag.*, 1879; Glazebrook, *Proc. Camb. Phil. Soc.*, 1883; Krüss, *Zeitschr. f. Instrumentenkunde*, 1898, 1904; Nutting, *Bull. Bureau of Standards*, Aug. 1906.

saying that the colours of the two illuminants were identical. Also, if the ratio were not unity, its value would give us a direct measure of the practical excess of any colour.

One of the most complete spectrophotometric comparisons of artificial illuminants with daylight of recent years is that undertaken by Nichols.[1] Seeing that daylight is itself somewhat variable, these results cannot be expressed with very great exactitude, but Table IV., derived approximately from some of the experiments of this authority, gives a good general idea of the variations to be met with. It brings out in a striking manner the preponderance in most artificial illuminants of the red end of the spectrum and the comparative weakness of the blue. In this table the figures throughout the spectrum of daylight (white sky) are taken as unity, and for the sake of comparison the ratio at $0{\cdot}59\mu$ is taken as unity also. An illuminant which had exactly the same colour as daylight would naturally give a unit ratio throughout the entire spectrum.

The spectrophotometric method of examination, while very exact and scientific, is somewhat elaborate and essentially suited for the laboratory. Attempts have been made to derive approximate results by the use of coloured glasses or gelatines with a photometer.[2] As a convenient method of research this has something to recommend it. But it is probably not so accurate as spectrophotometry proper. Table V., due to Voege, may perhaps be taken as typical of results obtained by these methods.

More recently a similar method has been used by Bloch and Jasse, who have tabulated the chief modern illuminants in terms of their resemblance to daylight. The chief point in these researches is the ingenious form of diagram used. Bloch arranges the illuminants within a rectangle whose co-ordinates denote the ratios red-green and blue-green. Jasse locates them within a triangle, the vertices of which correspond respectively with pure red, green, and blue light.[3]

A word or two may now be said regarding several methods of securing "artificial daylight." It has been mentioned that there are several artificial illuminants, such as acetylene and the inverted arc light, which are claimed to resemble daylight very closely. For many purposes a fairly close resemblance is doubt-

[1] *Trans. Amer. Illum. Eng. Soc.*, May 1908.

[2] Voege, *Illum. Eng.*, London, vol. v., Aug. 1912; Dow and Mackinney, *Photogr. Jour.*, April 1911.

[3] L. Bloch, *E.T.Z.*, 13th Nov. 1913; E. Jasse, *E.T.Z.*, 18th Dec. 1913.

TABLE V.—CONTAINING COMPARISON OF COLOURS OF VARIOUS ARTIFICIAL ILLUMINANTS (VOEGE).

Colour.	Daylight.			Electric Glow-lamp.				Petroleum.					Electric Arc Light.						Mercury-Vapour Lamp.		
	Cloudy Sky.	Blue Sky.	Sunlight.	Carbon-filament Lamp.	Tantalum Lamp.	Tungsten Lamp.	Nernst Lamp.	"Reform" Burner.	"Adonis" Burner.	Acetylene.	Incandescent Gaslight.	Hefner Lamp.	Ordinary Carbons.	Bremer Lamp.	Yellow Flame Carbons.	Red Flame Carbons.	White Flame Carbons.	"Daylight" Enclosed Lamp.	Ordinary Lamp with Glass Tube.	Ordinary Lamp with Rhodamine Reflector.	Mercury-Quartz Lamp.
Blue	1·00	1·65	0·65	0·20	0·21	0·23	0·24	0·12	0·15	0·27	0·23	0·09	0·75	0·07	0·24	0·45	1·05	1·18	0·77	0·97	0·58
Green	1·00	1·33	0·85	0·79	0·79	0·86	0·84	0·74	0·79	0·86	0·89	0·73	0·97	0·67	0·75	0·90	1·21	1·18	0·88	0·80	0·78
Yellow-green	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
Red	1·00	0·77	0·90	1·76	1·63	1·63	1·58	2·18	2·12	1·37	1·20	2·24	1·35	1·90	1·16	1·68	0·97	0·40	0†	0·62	0·04
Deep red	1·00	0·65	0·80	2·70	2·14	2·10	2·14	3·87	3·26	..*	1·13	3·9	1·70	0·87	..*	..*	..*	0·54	0†	0†	0†

* Measurement omitted. † Too small to measure.

less all that is necessary, and in the case of florists, linen-drapers, picture shops, etc., it does not seem necessary to aim at very great exactitude. But in certain trades what is needed is an illuminant which is not only identical with daylight in colour but absolutely constant and invariable. Some years ago screens were devised by Prof. Gardner of Bradford for use with enclosed arc lamps in order to imitate daylight, and the same method has now been applied to the tungsten incandescent lamp. H. E. Ives and M. Luckiesh,[1] in the United States, have found that this can be done by means of a screen composed of signal-green and cobalt-blue glass, in conjunction with a special gelatine film to correct the transmission band in the yellow. The specific consumption of such a lamp is given as 10 to 12 watts per candle, but this loss in efficiency might often be of small moment in comparison with the advantage of increasing the hours of work during which colour-matching can take place. Ives [2] in the United States and Thorn Baker [3] in this country have also been known to apply the same method to incandescent gas light, with apparently favourable results. Dr Kenneth Mees [4] in this country has likewise devised a special combination gelatine screen which is said to give a very exact form of artificial daylight. The absorption of light is stated to be about 85 per cent. At present it does not seem to be possible to convert the light from tungsten lamps into an exact replica of daylight without the use of gelatines and a very considerable absorption. Mr A. P. Trotter has, however, found that a fairly close resemblance can be secured by using suitable blue and green glasses, and in this case the loss of light is much less. More recently, several forms of daylight incandescent lamps, either using special tinted glass or dipped in appropriate solutions, have been introduced. The

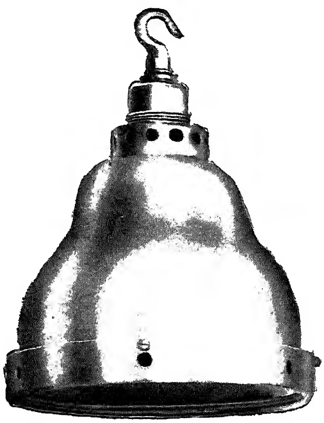


FIG. 73.—Benjamin daylight tungsten unit.

[1] "Subtractive Production of Artificial Daylight," *Illum. Eng.*, London, vol. iv. p. 394. See also *Journ. of the Franklin Institute*, May 1914.

[2] *Illum. Eng.*, London, vol. vi., June 1912, p. 339.

[3] *Ibid.*, Dec. 1913, p. 604.

[4] *Ibid.*, vol. v., Feb. 1912, p. 79.

resemblance to daylight seems fairly close, and the amount of light absorbed is said to be very much smaller than in the case of earlier attempts.[1] The advantage of the tungsten daylight lamp would seem to lie in its convenience. It is a simple matter to screen off a small part of the room, or arrange a cabinet provided with artificial daylight, while the rest of the room may be illuminated in the ordinary way. Fig. 73 shows the manner in which this unit is commonly conveniently made up.

There remains one other form of artificial daylight to be mentioned, namely, the Moore carbon-dioxide tube. This illuminant has only recently been introduced into Great Britain, although it is stated to have been largely used in the United States. An installation was recently put up in a hop merchant's office in the city of London. The colour of the light appears to the eye to be very similar to daylight, and this is said to be borne out by the experience of experts on colour-matching. The resemblance to daylight is accentuated by the fact of the light being spread over a very large radiating area, so that it gives practically no shadow. The inventor of this system, Mr D. Macfarlane Moore, has even advocated that the carbon-dioxide tube should be taken as the standard of white light. He contends the colour of this light, besides being so close to daylight, is exactly reproducible provided the nature and pressure of the gas and the electrical conditions are specified exactly.[2]

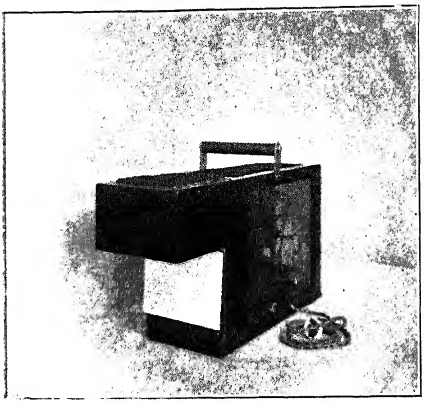


FIG. 74.

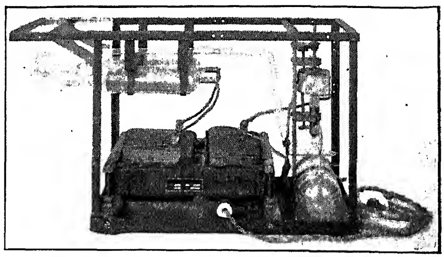


FIG. 74A.

New compact Moore light for colour-matching.

Weight, 35 lbs. Dimensions, 21″ × 7″ × 12″
Watts, 330. Illumination 100 ft.-candles (immediately under lamp).

[1] *Illum. Eng.*, London, vol. vii., Jan. 1914, p. 12; March 1914, pp. 152, 154.
[2] *Trans. Ill. Eng. Soc. U.S.A.*, April 1910.

A recent development has been the introduction of small and compact Moore tube outfits for colour-matching purposes. An installation of this type is shown in figs. 74 and 74A.

It is too early as yet to state with precision which of these various systems approaches most closely to actual daylight. To secure exact resemblance is by no means easy, but there are many cases in which it is only necessary to study a certain limited range of colours, and where even an illuminant which only resembles natural light approximately may be very serviceable.

A matter of some importance in the study of this subject is the preparation of a complete graduated scale of specimen colours. One of the best and most complete series of this kind is the *Répertoire de Couleurs* issued by the Société Française des Chrysanthémistes, and used by the Royal Horticultural Society in this country. The volumes contain a remarkably complete series of coloured plates, each colour being reproduced in a variety of shades, numbered and named in four languages.

Practical Applications of Coloured Light.

We have seen that a certain sacrifice in efficiency is necessary in order to secure "white light." For ordinary purposes of illumination a more or less white light and a continuous spectrum are usually desirable. There are, however, certain cases in which the question of colour is of secondary importance, and the *brightness* of the light is the chief point to be considered. For example, in the illumination of large open spaces, docks, factory-yards, etc., this is often true, and it is conceivable that in the future we might devise an illuminant giving only the highly efficient yellow-green rays for which, as Nutting has shown, the sensitiveness of the eye is a maximum; such a source should theoretically be capable of developing 64 c.p. per watt.

On the other hand, there are also cases where light of a certain colour has distinct advantages. It will be remembered that in the last chapter acuteness of vision was shown to be connected with colour. Here is a good illustration of the value of *quality* as distinct from quantity of light. It may be that by using monochromatic rays for certain fine work we should be able to see more clearly than by the aid of the whole spectrum; it is obviously no good producing rays which the eye is unable to bring to a focus.

Another quality of light which seems to depend to some

extent on colour is "penetrating power." A great deal of controversy on this subject has taken place between the representatives of gas and electric lighting. The old discussion of the comparative merits of gas and electric street-lamps in fogs has not led to any very definite conclusions, chiefly because quite a number of different questions are confused together. For instance, the distribution of light in the two cases may be different. One also finds that many of the complaints that arc lamps were unsatisfactory in a fog were based on the objections that the standards were too high or the lamps spaced too far apart—matters quite distinct from "penetrating power" properly understood. Readers will also recall the old controversy regarding the relative merits of oil, gas, and electric lighting for lighthouse work, terminating in the appointment of a Royal Commission. This commission reported in 1890.[1] It was agreed that the light from the carbon arc light possessed somewhat less penetrating power than the redder rays from gas illuminants. Nevertheless, electric light was recommended in cases where very great brightness was desirable.

On general grounds there is good reason to believe that the rays from the red end of the spectrum possess somewhat better penetrating power than those in the blue. For it is a well-known scientific principle that the ability of light to turn corners and work its way among a series of small particles is proportional to the wave-length. Thus light waves cast sharp shadows, but wireless electric waves (which are merely light waves of very great wave-length) can readily penetrate solid objects. Many illustrations of the application of the same principle in Nature might be mentioned. The blue colour of the sky is popularly ascribed to the reflection to and fro amid the small suspended particles of dust of the obstructed blue rays; the transmitted light, on the other hand, is golden. In the same way at sunset the light penetrating through the clouds is golden or even red in colour, while the intervening atmosphere becomes filled with a luminous blue haze, so that distant dark objects appear blue. It is likewise a common experience that bright objects seen through smoke, milky liquid, or finely suspended particles of any kind tend to appear red; seen by reflected light, on the other hand, smoke and finely precipitated white particles appear to have a blue or purple tint. This circumstance has a certain bearing on the absorption of opal-

[1] *Jour. of Gas Lighting*, 4th Nov. 1890.

escent globes. A piece of white opal illuminated by the light of the mercury-vapour lamp looks distinctly purplish. When the lamp is enclosed in a dense globe the change in colour of the transmitted light, owing to the absorption of the blue ray, is also very marked.

The colours of most illuminants yielding continuous spectra are so broadly similar that it seems doubtful whether their penetrating power can vary very greatly. But should we in the future find ourselves able to restrict the radiation of an illuminant entirely to the red and orange rays, a distinct gain might perhaps result. The low penetrating power of the ultra-violet rays and their ready absorption by the atmosphere have already been mentioned. It appears that the powerful action of these rays on the outer skin is due partly to their being so readily absorbed; according to some authorities it is desirable in treating some diseases to mix a certain amount of the more penetrative visible violet rays with the ultra-violet in order to reach the underlying tissues.

Cases are also met with in practice in which the colour of the surroundings is the essential factor. If, for instance, we wish to illuminate objects which only reflect green light, it is clearly of little value to use red rays. One does not often meet instances in which monochromatic light is advisable. But there are circumstances in which it might be beneficial to restrict the light and to aim at producing one part of the spectrum in special quantity. For the illumination of parks and gardens, in which we desire to bring out the colours of the green leaves and grass, one might naturally select an illuminant which was rich in green rays, such as the mercury-vapour lamp. Similarly, in the case of illuminated signs in which large yellow and orange surfaces are to be lighted up, flame arcs would be found to give a very vivid effect. Occasionally the special strontium flame carbon arcs, giving a very crimson light, have been found acceptable for butchers' shops.

On the other hand, one can imagine cases in which it is desirable to use light of a colour which is not readily reflected. Steinmetz has made the suggestion that the stain of age on materials is usually due to deposits of iron and carbon, and, being of a reddish brown colour, reflects rays from the red end of the spectrum better than those from the green end. A ruddy tinge is therefore an advantage for the illumination of a blacksmith's shop or foundry, since a fair proportion of this quality

of light is reflected from the surroundings. Such stains (according to this view) appear particularly sharply defined when illuminated by green light, especially if they occur on somewhat greenish materials. It has also been suggested that green light might, for the same reason, be useful to the physician in enabling him to detect a faint incipient rash on the skin such as could not be seen clearly by ordinary light.

These are points which await confirmation. But we do meet the same effect very frequently in practical lighting problems. In selecting the wall-paper for a room it is often distinctly advisable to bear in mind the illuminant to be used, and especially the shades employed with the illuminant. If, for example, we select a deep blue-coloured paper for a room which is to be lighted by oil lamps (which are relatively weak in blue rays) we not only fail to secure any material assistance in the form of reflected lights from the walls, but probably also find that the colour and pattern of the paper is very poorly brought out. If a tungsten electric lamp or incandescent mantle were used the results might be better; but many dark blue wall-papers which appear all right by daylight are unsuitable for most artificial illumination. By gas or electric light they have a distinctly funereal effect.

The colour of the wall-paper ought also to be borne in mind in selecting the shades for the lamps. It is usually not desirable to choose a shade of a very widely different colour from the paper. If, for example, the wall-paper is a pronounced green and deep red shades are used, the result is that very little light is reflected from the walls, and their colour may also be distorted in a somewhat sickly manner.

All this illustrates the importance of bearing in mind the changed appearance of colours by artificial light. But there are other effects less easily foreseen. A large area of strongly coloured paper does not appear quite the same as a small sample. This is probably due in part to the fact of the image of the coloured material occupying a much larger area on the retina; also to the "mass effect," *i.e.* the effect of large masses of colours on each other. The colour of light reflected to and from surfaces of a very intense tint tends to become more and more accentuated. In a room papered entirely in red, what we see is not red paper illuminated by white light, but eventually red paper illuminated by red light, which produces a distinctly different effect.

In general it is wiser, if the amount of light in a room is

of much consequence, to avoid very deeply coloured papers. Reflection from the walls and ceiling of a room constitutes a very valuable and natural method of diffusing the light. Table VI., based on data originally worked out by Dr Sumpner and given in Dr Bell's well-known book,[1] gives some idea of the comparative assistance to be derived from various kinds of reflecting material :—

TABLE VI.—REFLECTING POWER OF VARIOUS COLOURED MATERIALS (COMPILED BY SUMPNER).

White blotting-paper	82 per cent.
„ drawing-paper	80 „
Ordinary foolscap	70 „
Cream paper	56 „
Light orange paper	50 „
Plain deal wood (clean)	45 „
Yellow wall-paper	40 „
Light pink paper	36 „
Light emerald-green paper	18 „
Dark brown paper	13 „
Vermilion paper	12 „
Dark green paper	5 „
Maroon paper	5 „
Deep blue paper	3·5 „
Black cloth	1 „
„ velvet	0·4 „

This table is compiled for white light, and will naturally vary according to the artificial illuminant used.

Reference has already been made to the curious psychological influence of colour, the impressions of "warm" and "cold" tones, for which there may be some scientific basis. It is also stated that the want of achromatism of the eye causes blue objects to appear somewhat more distant than red ones. A well-known experiment in physiological optics consists in looking at a blue patch on a red ground; the blue patch appears to recede, although really in the same plane. Blue-coloured surroundings therefore tend to create an impression of distance and vastness. It is said that a room papered with red paper appears smaller than the same room papered in blue or green would do.

When, however, we attempt the selection of harmonious combinations of colour we must usually trust to the artistic sense of the gifted few. It is doubtful whether our increasing knowledge of the intricacies of the eye and the processes of the brain

[1] *The Art of Illumination.* See also L. Bell, paper read before the Convention of the Illuminating Engineering Society in Boston, U.S.A., 1907.

will ever enable us to explain why certain colour combinations produce an agreeable sensation and others the reverse. Possibly the unpleasant impression received by the artistic eye when viewing colours that "clash" is based upon the chemical changes that occur in the retinal substances.

The possibilities of coloured light for decorative purposes have not yet been completely exploited. Light is being used

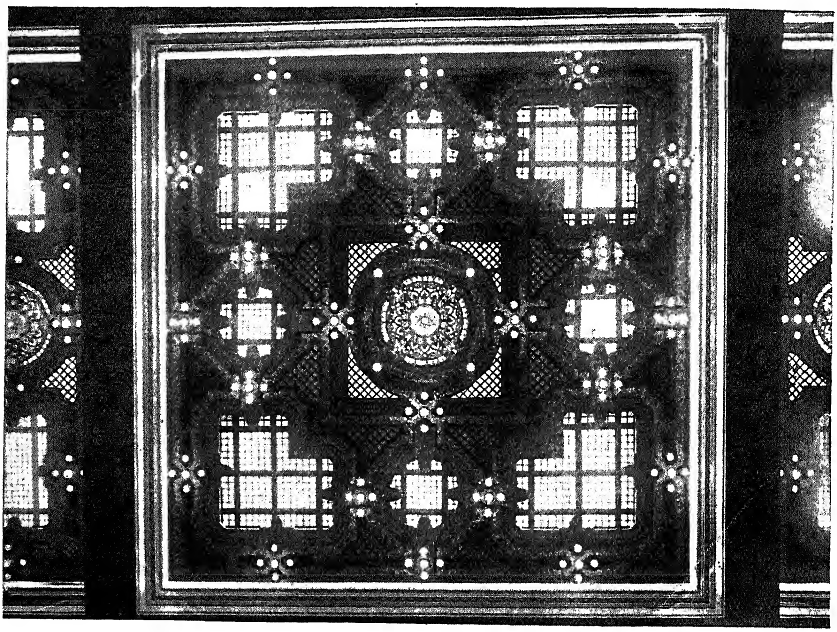


FIG. 75.—The coloured glass ceiling used to illuminate the auditorium, Allegheny County Soldiers' Memorial, Pittsburgh.

to an ever-increasing extent for advertising and spectacular purposes, but the tendency has hitherto been to aim at increasing brilliancy rather than to make use of colour effects. Yet there can be no question that the scope in this direction is infinitely greater than it was a few years ago.

Now that we have available such sources as the mercury-vapour lamp, yielding (with suitable screens) green, yellow, or blue monochromatic light; the neon tube, producing vivid orange-scarlet rays; and the Moore tube and flame carbon arc lamps, capable of producing various colours according to the constituents used, much can be done that was formerly impossible.

A remarkable instance of the use of colour for interior decorative lighting is furnished by the illumination of the Allegheny County Soldiers' Memorial building at Pittsburgh, designed by Mr W. Bassett Jones. The two views selected show respectively the lighting of the banqueting hall and the construction of the ceiling. The method of lighting has itself very distinctive features, but the colour effects attempted are perhaps

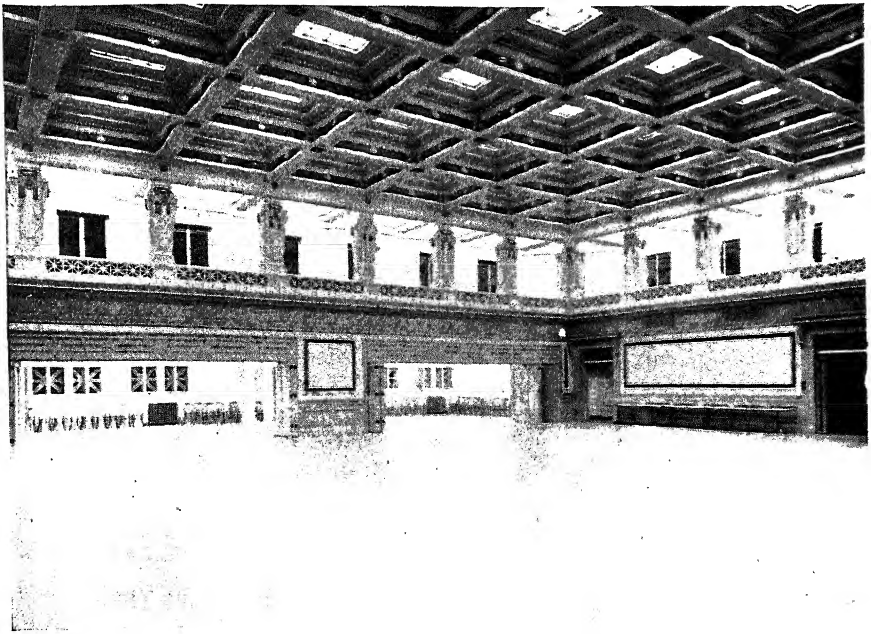


FIG. 76.—View of the banqueting hall, Allegheny County Soldiers' Memorial, Pittsburgh.
(Taken by artificial light.)

still more interesting. The novel feature in the colour design has been the premeditated combination of the colours of the walls with the light of the illuminants used. The auditorium derives its illumination mainly from an elaborate coloured glass panelled ceiling, shown in fig. 75.

The ceiling consists of nine distinct panels, surrounded by rich moulding and designed in amber glass. Above this diffusing glass yellow flame arcs are placed, and it is said that the occasional flickering is actually an advantage, since it gives a scintillating jewel-like effect. In addition to this, the ceiling is studded with frosted carbon-filament lamps, and a nitrogen

Moore tube is used to outline the panels with a border of pinkish light. There are also panels in the side walls above the high windows, each of which is fronted with blue glass and contains a mercury-vapour lamp. The light from these panels is used to give the walls of the auditorium a sky-blue tone. The method of illumination throughout the entire building is said to have been schemed out in harmony with the intentions of the architect, causing the mouldings to stand out well and the pillars and carving in the rooms to be clearly seen. The illustrations show that the actual sources are invariably screened from the eye; it is only the illuminated surfaces adjacent to them that are seen. The following figures for the auditorium lighting may be of interest [1]:—

Conditions of Lighting.	Illumination on Floor (foot-candles).
(1) All lamps in use	3·82
(2) Exposed incandescent lamps and sashes	3·10
(3) Sashes only	1·46
(4) Exposed incandescent lamps only	1·74
(5) Nitrogen tubes only	0·40
(6) Flaming arc lamps only	0·30

When all the lamps are lighted the illumination at the floor level is stated to be an approximate white in colour; the total power consumption is given as about 6·3 watts per square foot of floor area.

The production of colour-effects is apt to require a considerable amount of energy, and it is easy to understand why this should be the case. The method of producing blue light hitherto used has been to produce a very intense white light, and then to introduce a blue screen so as to cut off all but the blue rays. Now, these rays may constitute as little as ½ per cent. of the total candle-power of the source—or even less. When we consider that probably less than 1 per cent. of the energy given to the source is reproduced in the form of light, and that this energy in turn is only a very small proportion of that derived from the coal at the generating station, it is evident that the percentage of the original energy ultimately utilised is exceedingly minute—perhaps as little as 1/25,000th.

The introduction of the principle of selective radiation, as exhibited by the mercury-vapour lamp, opens out considerably greater possibilities, since it suggests that we are on the way

[1] *Trans. Illum. Eng. Soc. U.S.A.*, Jan. 1911.

towards producing only the particular wave-length we desire. We cannot doubt but that the possibilities of producing very intense monochromatic light would lead to new and hitherto unsuspected applications of colour. As an example, take the case of the ultra-violet rays. At one time it was difficult to secure these rays in any quantity. Even in the arc lamp the energy available in this form is possibly but a small percentage of the whole, while in most incandescent illuminants it is actually a fraction of 1 per cent. But the invention of the quartz tube mercury-vapour lamp provided us with a source far richer in ultra-violet energy than was available before. According to Ladenburg, as much as 30 per cent. of the total energy developed is available in this form.[1] As a result, all manner of new applications for these rays are being discovered. They are said to have proved beneficial in therapeutic work, for sterilising water and destroying bacteria, for tanning leather, and other purposes. In fact, it would seem that the operation of these rays might actually be instrumental in the formation of new branches of chemical industry, since by their aid chemical changes can be brought about which could not otherwise be produced. We have already alluded (p. 180) to the wonderful fluorescence effects that can be produced through the agency of ultra-violet rays. But perhaps their most interesting application is in contesting the permanency of colours. We know that colours tend to fade when exposed to strong light. For this reason people often pull down the blinds in their drawing-room when it is not in use in order to save the wall-papers and carpets. This change is due to the "photoresonance" of the colouring material under the action of the ultra-violet. The unfavourable climatic conditions in the north of Germany have in the past proved a difficulty to the colour manufacturers in that district. It was necessary to send their materials down to the sunny south, where plenty of bright sunlight was available, so that they might be exposed to the light for a sufficient length of time to test the permanency of the colours. But it is now suggested that the utilisation of the new artificial sources of ultra-violet light will make this unnecessary, and that such tests can be carried out independent of climatic conditions, and in as many days as months were formerly necessary.

Now it is quite possible that if we were to find a way of

[1] *Physikalische Zeitschrift*, v. p. 525, 1904.

obtaining efficiently very large quantities of pure blue or pure red radiation, all sorts of special effects of these kinds of light might be revealed. For example, we should have a much better chance of investigating the curious psychological and physiological influences commonly attributed to these rays, and of ascertaining their effect on plant life. At present we have usually to work with more or less mixed light (and even this in comparatively small quantities), which is apt to obscure the results of researches in this field. Or, again, if we could produce the highly luminous yellow-green radiation *only*, there would be many cases in which an intensity of illumination far beyond that practicable at present would be attempted. For beacons and searchlights and other work, where brilliancy is the main essential, such a source would have great possibilities and we cannot doubt that many other applications would soon be found.

In the future we shall probably come to realise that it is almost always necessary to consider not only the *quantity* but the *quality* of the light required for any specific purpose. We are still far from our ideal in this respect. At present we are in the position of a man who cannot strike one note on the piano without at the same time pressing down a vast number of other keys. Possibly a time will come when we shall be able to control our sources completely, to compel them not only to provide us with the intensity of light we require, but to give out successively rays from any part of the spectrum—"to play upon the visible gamut of light with the same ease and certainty as upon the audible octave."

CHAPTER VII.

THE MEASUREMENT OF LIGHT AND ILLUMINATION.

The Nature of Photometric Measurements, and the necessity to appeal to the Eye—Standards of Light, Flame and Incandescent Standards, their merits and drawbacks—Relations between the Units of Candle-power used in various Countries and the "International Candle"—Fundamental Laws of Light Distribution, the Inverse Square Law and the Cosine Law, and their Limitations—Units of Illumination, Luminous Flux, Brightness, etc., and proposed Standard Nomenclature—Direct and Diffused Reflection—The Photometric Bench and usual Methods of Measuring Candle-power—Photometers, possible Sensitiveness and Accuracy—Rumford, Ritchie Wedge, Bechstein, Bunsen, and Lummer-Brodhun Instruments—Flicker Photometers, work of Rood and Whitman—Krüss, Bechstein, Wild, and other modern types—The Problem of Colour Photometry—Problems introduced by new Illuminants, such as the Neon and Mercury-Vapour Tube Lamps, physiological difficulties involved and various methods of overcoming them—Physical Photometers, possibilities of using Photography, Thermopile or Selenium cell—Distribution of Light from Illuminants, methods of determining Polar Curves and Mean Spherical Candle-power—Matthews, Blondel, and Ulbricht globe integrating appliances—Measurement of Illumination, its value in practice—Early Photometers, Preece and Trotter, and Acuteness of Vision Illuminometers—Principles in the design of Illumination Photometers, Trotter, Harrison, Martens, Weber, Sharp and Millar, and other instruments—Surface Brightness Photometers, Holophane Lumeter, Lightometer, and Luxometer, etc.—Discussion of the use of such Instruments, measurements in Schools, Libraries, Factories, etc.—Recommendations of the Verband deutscher Elektrotechniker on indoor and outdoor measurements, measurement of Illumination in the Streets—Daylight Photometry, suggested methods of relating indoor illumination to the unrestricted illumination outside, application to ancient light cases and architectural problems.

It has been well said that every science passes through three stages. In the first we merely observe and record isolated facts, in the second we associate these facts together and derive laws, and in the third we define these laws with precision and establish numerical relations. In order to arrive at the final stage we must know how to measure.

The science and art of illumination may be said to have now arrived at the third stage. At one time photometry was regarded merely as an interesting and fascinating study for the

professor in the laboratory. To-day it is a process of industrial importance. New illuminants have come to the fore, and new methods of employing them are constantly being devised—and how can we compare their merits without methods of measuring the light derived from them? Whatever be the method of lighting adopted, it is the illumination derived from it with which we are concerned, and for which we pay. Measurement of this commodity would therefore seem to be an elementary safeguard, to be observed in any contract relating to the sale of light.

The growing practical importance of photometry has led to the publication of quite a number of text-books on the subject.[1] Some of them cover the ground very fully.

In this chapter we shall confine ourselves mainly to the principles of photometry, pointing out as far as possible where fuller details may be found.

What is it we Desire to Measure?

In the first place it is necessary to determine clearly what we propose to measure, for on this decision depends the nature of our measuring apparatus. The uses of light are various. It has been suggested that photometers might be based on the "power of revealing detail" of illuminants—for example, that a lamp might be said to have a certain value if it enabled us to read type of a specified size. But a very little experience shows that such a method has grave defects. It introduces the personal element, *e.g.* the acuteness of vision of the observer; it lacks accuracy and precision; and we have seen in Chapter V. that the eyes of some people are unable to focus light of certain colours; in such a case it might be impossible to see an object clearly, however bright the illumination of the object may be.

In the early days of photometry experiments were sometimes made with photographic paper. But such a test measures the

[1] See, for example—A. P. Trotter, *Illumination, its Distribution and Measurement*, 1911; A. Palaz, *Traité de photométrie industrielle*, 1892 (also published in English); E. Liebenthal, *Praktische Photometrie*, 1907; W. M. Stine, *Photometric Measurements*, 1900; F. Uppenborn, *Lehrbuch der Photometrie*, edited by B. Monasch, 1912; Dr J. A. Fleming, *Photometry of Electric Lamps* (Paper read before the Institution of Electrical Engineers, London, 1902), this contains an excellent list of references; C. H. Sharp and E. B. Rosa, *The Measurement of Light, Photometric Units and Standards* (Lectures delivered at the Johns Hopkins University, Baltimore, U.S.A., 1910).

actinic power of the chemical rays in an illuminant rather than the luminous effect of the visible rays. In practice it is usually very tedious. It has also been suggested that the effect of radiant energy on the thermopile or the selenium cell might be employed. But all such "physical" apparatus, besides being inconvenient in practice, is open to the objection that it does not "see" the energy impinging upon it in the same way as the eye.

The more we consider the problem, the more evident does it become that any general method of measuring light must be based upon the perception of the eye. It is now generally recognised that such effects of light as photographic action, influence on acuteness of vision, power of penetrating fog, etc., demand special tests. In practice we usually confine ourselves to measuring what is undoubtedly the most useful function of light—*the power of creating brightness.* By this, of course, is meant the brightness of surroundings, not the brilliancy of the lamp itself. Some people are apt to judge the efficacy of an installation by the appearance of the lights. This is a mistake. Such a judgment is usually based mainly on the intrinsic brilliancy (candle-power per square inch) of the sources, and we have seen in Chapter V. that there is every reason to keep this value low, with a view to avoiding glare. The natural function of a lamp is to illuminate its surroundings, and it is the capacity of a source in this respect that we desire to measure.

At present we are obliged to fall back on a purely comparative method of judging an illuminant. We merely present a surface at a given distance from each of the lamps to be compared; and if the surface appears to the eye equally bright in both cases, we say the two lamps have the same intensity. In order to carry out this operation two implements are obviously necessary. We must have (1) some standard source of constant intensity to which all other sources of light can be referred: and (2) some appliance assisting the eye to perceive the exact point at which equality of brightness occurs. Such an instrument is termed a photometer.

Standards of Light.

The earliest recognised official standard of light was the Carcel oil lamp. This was used by Regnault and Dumas for testing gas in 1800, and is still used in France as the official

standard. In England we first had recourse to the standard candle, which came into existence to meet the needs of the early legislation on the testing of gas. The intensity of lamps thus came to be expressed in "candles," and gas coming up to the legal requirements was described in this way.[1]

The standard candle was prescribed to be of a certain weight, and to burn so many grains of spermaceti per hour.

But it was soon found that it formed a very indifferent standard. The light yielded by it depended to a great extent on the adjustment of the wick, and on the atmospheric conditions. To this day we still lack the ideal absolute standard. But various lamps have been introduced that are decidedly more accurate than the standard candle. These are described in detail in various works devoted to photometry. In France the Carcel lamp, in Germany the Hefner amyl acetate lamp introduced by Hefner von Alteneck, in England and America the ten candle-power pentane standard invented by Prof. Vernon Harcourt are used. The Harcourt lamp is described as the official standard of the Metropolitan Gas Referees and the unofficial British standard.

We still retain the word "candle-power," and the unit in common use to-day is approximately equal to the light yielded by the old standard candle.

A distinction should be drawn between a unit of light and a standard. Although the standards employed may differ, the unit of light employed in Great Britain, France, and the United States is now the same, and is sometimes termed the "international candle," although the term has not yet received international sanction.

The relations existing between this and the older units of light are as follows:—

	Hefner Candles.	Carcel Candles.
Proposed international candle	1·11	0·104

There was formerly much uncertainty as to the relations between the units in various countries. But as a result of the excellent work accomplished by the four accredited laboratories—the Technische Physikalische Reichsanstalt (Charlottenburg)

[1] It has become usual to speak of sources as having "so many candle-power." This expression is embodied in many formulæ, and it was therefore convenient to retain it in some of the chapters in this book. But strictly the term "candle-power" should only be used in a general sense as equivalent to intensity, and it is more correct to say that a source gives "so many candles."

in Germany, the National Physical Laboratory (Teddington) in England, the Laboratoire Central d'Électricité (Paris) in France, and the Bureau of Standards (Washington) in the United States—the relations have become quite definite. The recent history of these units was summarised in a paper before the Physical Society (London) by Mr C. C. Paterson in 1909.[1]

Another source of uncertainty, that has only recently been completely elucidated, was the effect of atmospheric conditions on flame standards. It is well known that decreased barometric pressure diminishes the light from a flame (it is said that a candle flame at the height of Mt. Blanc is almost as invisible as a spirit flame). The pressure of water-vapour and carbon dioxide have a similar effect, and all these quantities vary from day to day. Vitiation of the atmosphere of the photometer by causing a deficiency in oxygen in a room likewise reduces the light given by a flame standard.[2]

The effects of humidity and barometric pressure on the Hefner lamp were worked out by Dr E. Liebenthal as far back as 1895.[3] The corresponding effect on the Pentane lamp was first studied by Mr C. C. Paterson in this country.[4] More recently Mr A. P. Trotter, in conjunction with Mr W. J. A. Butterfield and Prof. J. S. Haldane,[5] adopted the expedient of confining the lamp within an air-tight chamber, so that the pressure and atmospheric conditions could be varied within far wider limits than are met with in practice. By this means it was possible to confirm Mr Paterson's result. Trotter finds that the following changes in barometric pressure, humidity, and carbon dioxide in the air would ordinarily cause a diminution of 1 per cent. in light:—

	Pressure.	CO_2.	Aqueous Vapour.
Pentane lamp,	− 12·5 mm.	+ 0·035 per cent.	+ 0·16 per cent.
Hefner ,,	− 25·0 ,,	+ 0·045 ,,	+ 0·16 ,,

It will be seen that although a flame standard is by no means constant, yet it is possible by the aid of the above knowledge to allow for any deviation from the standard

[1] *Proc. Phys. Soc. London*, vol. xxi. For a collection of references to the earlier units see F. Uppenborn, *Lehrbuch der Photometrie* (1912), p. 32.

[2] See Dow, *Elec. Review*, 28th Sept. 1906.

[3] E. Liebenthal, *Zeitschr. für Instrumentenkunde*, vol. xv., 1895, p. 157.

[4] *Electrician*, vol. v., 1904, p. 751; 1907, p. 157. For some more recent investigations see also a paper by E. C. Crittenden and A. H. Taylor, *Trans. Amer. Illum. Eng. Soc.*, vol. viii., 1913, p. 410.

[5] Paper presented before the Int. Photometric Com. (Zürich), July 1911.

atmospheric conditions. From the report of the National Physical Laboratory for 1912 it appears that the value of the unit derived from the Pentane lamp can now be held constant within 0·1 per cent.

On the other hand, there are those who maintain that the ideal standard should be an incandescent one, electrically controlled and absolutely independent of climatic conditions. Attempts to devise an absolute standard of this kind based on the use of incandescent platinum have been made by Violle[1] and Petavel,[2] but the experimental difficulties have hitherto proved insuperable. Experiments have also been carried out at the Bureau of Standards with tubes containing helium gas. Interesting results have been secured, but it is too early as yet to judge of the practicability of such tubes as a standard.[3]

Of late years a great deal has been done with incandescent electric glow-lamp standards. The use of large bulb lamps of this kind was first described by Dr Fleming in 1902, and such lamps were prepared by the Ediswan Company under his supervision even earlier than this.

It is now customary to use a number of carefully aged electric incandescent lamps, and this forms a convenient means of checking the constancy of flame standards. As a result of experiments at the Bureau of Standards, Rosa and Middlekauf believe that the unit of light might be maintained constant for a century by this means.[4]

A great advantage of the electric lamp is its portability. Calibrated lamps have been circulated among the laboratories in the chief European countries and the United States, and this has proved exceedingly useful in preserving the relation between the units of light.

A distinction should also be drawn between primary and secondary standards. The Pentane standard is rarely used continuously for any length of time. The usual course is to compare it with some other lamp, which then becomes a "secondary standard." This is used continuously and checked at frequent intervals. In testing electric lamps one naturally

[1] *Comptes Rendues*, 1879 and 1883.

[2] *Proc. Roy. Soc. London*, 1899.

[3] P. G. Nutting, *Bull. Bureau of Standards*, Washington, Dec. 1907 and Nov. 1912.

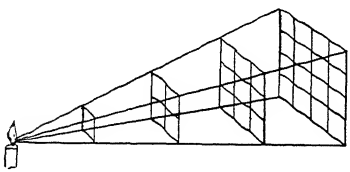
[4] Paper read before the Am. Institution of Elec. Engineers, 1st July 1910; *Illum. Eng.*, London, vol. iii., 1910, p. 547.

prefers to use a calibrated glow-lamp for the sub-standard; in a gas laboratory, on the other hand, an Argand or Methven burner is more generally used. In these circumstances the standard and the lamp under test will *both* be affected by fluctuations in electric pressure or variations in atmospheric conditions respectively, and errors due to these changes to a great extent eliminated. In illumination photometers small metal-filament electric glow-lamps are almost invariably used.

The Fundamental Laws of Light Distribution.

The next thing that we desire in comparing illuminants is a knowledge of the two fundamental laws of light distribution.

The first of these—the inverse square law—states that the amount of light striking a surface is inversely proportional to



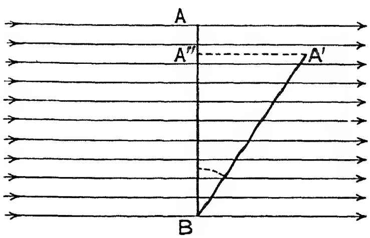


Fig. 77.—Illustrating inverse square law. Fig. 78.—Illustrating Lambert's cosine law.

the square of its distance from the source. If, for example, we *double* the distance of a lamp from a sheet of paper, the surface will only receive *one quarter* of the light that reached it before.

The truth of this law is conveniently illustrated in fig. 77, which is taken from Mr Trotter's well-known work on illumination. Suppose that, at a distance of 1 foot, the rays of light will cover a square of small dimensions, then at twice the distance they will enclose an area four times as great; and an area sixteen times as great at four times the distance. The same amount of light has thus been spread over areas respectively four and sixteen times as great as that of the original square, and the brightness has been proportionately diminished.

The second law (known as the "cosine law" or "Lambert's law") has to do with the inclination of the surface. If the surface occupies the position AB (fig. 78), so as to receive the rays of light vertically, the amount of light received will be a maximum. But if the surface is tilted into the position A′B, it

will only receive an amount of light proportional to its projected area A″B. Trigonometrically expressed, this means that the amount of light is proportional to the cosine of the angle at which the surface is inclined to the normal (the angle of incidence).

These two laws have reference only to the amount of light received by the surface. The *brightness* will also depend on the nature of the surface (*e.g.* its reflecting power), and on whether it is of a mat or glossy texture. This fact must be borne in mind in interpreting the cosine law.

It will also be observed that the application of the inverse square law assumes that the rays considered emanate from a point. If the distance of the surface from the illuminant is fairly great, it is usually quite sufficiently accurate to regard the source of light as a point. For example, ordinary electric glow-lamps and incandescent mantles can be considered in this way. But when we are dealing with clusters of lamps and mantles, or with sources surrounded by a diffusing globe of considerable dimensions, some care must be exercised in selecting the point from which measurements are made. In the case of the indirect system of lighting, where the illuminated ceiling becomes the source, or such illuminants as the Moore light, consisting of a tube of very considerable dimensions, the inverse square law is inapplicable. It is possible to divide the luminous area into short sections and treat each portion separately as a point; but the process is tedious. It is usually preferable to compare such systems on the basis of the actual illumination obtained in practice in a room of given area.

For some formulæ enabling the illumination from large light-giving areas to be calculated, readers may be referred to an address by Prof. Silvanus P. Thompson,[1] and a paper by Mr W. Basset Jones.[2]

It must also be remembered that the inverse square law only applies strictly to sources which radiate luminous energy uniformly in all directions. When the light is concentrated in one direction by means of lenses and mirrors the ordinary formula may not apply. Difficulties in this respect are sometimes met with in the photometry of lamps equipped with focussing reflectors. An extreme case is presented by the search-light using a parabolic mirror and giving an approximately parallel beam

[1] *Illum. Eng.*, London, vol. ii., 1909, p. 824.

[2] *Trans. Illum. Eng. Soc. U.S.A.*, vol. iv., 1909, p. 230.

With a strictly parallel beam the amount of light received by a surface would be (save for atmospheric absorption) actually independent of distance from the source.

The effect of atmospheric absorption deserves mention. In the ordinary photometry room the effect is almost always negligible, although the authors have met traces of it during foggy weather when the distance between the lamps was unusually great. But in outdoor work, *e.g.* in testing street lamps and search-lights, foggy weather naturally causes considerable difficulties.

Illumination and some Derived Units.

Illumination.—It is convenient to express the inverse square and cosine laws in algebraic form.

If the intensity of the source be I candles, its distance r feet, and θ the angle of incidence at which the rays strike the surface illuminated, the illumination E (*i.e.* the quantity of light striking the surface per unit area) is given by the formula:—

$$E = \frac{I}{r^2} \cos\theta \quad \text{foot-candles.}$$

The "foot-candle" is the unit generally employed in English-speaking countries and denotes the illumination derived from a source of 1 candle at a distance of 1 foot. It will be observed that this quantity can be specified quite independently of the arrangement of lights producing it. For example, it was stated in Chapter V. that an illumination of 2 to 3 foot-candles is desirable for reading purposes; but this illumination might be produced in an infinity of ways, *e.g.* by a local shaded light, by a number of lamps hung near the ceiling, or by indirect lighting, etc.

The expression "foot-candle" (although from a scientific standard by no means an ideal term[1]) has now become very general in English-speaking countries. On the Continent the "metre-candle" (*i.e.* the illumination derived from a source of one candle at a distance of 1 metre) is the usual unit. The metre-candle is now more generally known as the "lux." This term avoids the inconvenience of a compound word, and appears to have been first suggested by Sir William Preece at the Electrical Congress in Paris in 1889.

Owing to the difference of units of light employed in France

[1] See Trotter, *Illumination, its Distribution and Measurements*, p. 16.

and Germany, we find both an "international" lux and a Hefner lux in existence. Their relation to the foot-candle may be tabulated as follows:—

	Inter. Foot-candle.	Inter. Lux.	Hefner Lux.
"International" foot-candle	=1	10·76	11·95
" lux (metre-candle) . .	=0·0929	1	1·11
Hefner lux (metre-candle)	=0·0837	0·902	1

There are other units of illumination (Hefner-foot, Carcel-metre, etc.), but they have now practically fallen into disuse.

Luminous Flux.—At this stage it may be as well to mention several other units employed in illuminating engineering calculations.

The first of these is the unit of flux of light. Referring back to fig. 77, it will be noted that while the intensity of illumination varies according to the distance, the product of the illumination and the area remains constant. This is a natural consequence of the fact that there is a certain constant "flux" of light contained within the four radiating lines enveloping these successive areas.

It is sometimes convenient to deal with the total flux of light received by a surface. The unit flux of light is that received by an area of 1 square foot, illuminated with an intensity of 1 foot-candle, and is termed 1 "lumen." Thus, if an area of 5 square feet is illuminated with an intensity of 2 foot-candles it receives $5 \times 2 = 10$ lumens.

The flux of light, usually denoted by the symbol Φ, may be expressed in another way. Let A denote the illuminated area. Then referring back to the formula for illumination,

$$\Phi = \mathrm{EA} = \frac{\mathrm{IA} \cos \theta}{r^2} = \mathrm{I}\omega,$$

where ω is the solid angle subtended at the source by the area illuminated.

Mean Spherical Candle-power.—This definition leads us to the "mean spherical candle-power." Mathematically this expression is equivalent to surrounding the source with an enclosure of any shape, adding up the flux of light received on each element of this enclosure, and dividing by the entire solid angle through which this flux is received, 4π. The intensity of sources in general varies considerably in different directions. It is therefore hardly possible to compare them with any precision in terms of any particular ray. But we can do so by taking into account the

light in all directions, *i.e.* on the basis of mean spherical candle-power. *This quantity is defined as the candle-power which a source would possess if it gave out the same total flux of light as at present, but evenly in all directions.*

The mean spherical candle-power is denoted by the symbol I_0. Clearly the total flux of light from a source will be obtained by multiplying this quantity by the total solid angle 4π, through which it is emitted; in other words, $4\pi I_0$ = total flux of light.

It has already been observed that in some cases (*e.g.* the Moore tube) the definition of the "candle-power" of a source presents considerable difficulties, owing to the fact that it occupies such a large area; while in other cases, *e.g.* the search-light, the term has drawbacks, owing to the fact that the inverse square law does not rigidly apply. But in both cases the flux of light from the source is a perfectly definite quality, although its determination may present difficulties.

Direct and Diffused Reflection.—It was explained on p. 210 that the fundamental "inverse square" and "cosine" laws have only to do with the amount of light reaching the surface. When we pass on to consider its resultant brightness we find that allowance must be made for a new factor—the nature of the surface itself.

The brightness of a surface depends firstly on its reflecting power. Dr Sumpner's oft-quoted researches[1] on this subject gave the following results:—

Material.	Reflecting Power.
White blotting-paper	82 per cent.
,, drawing-paper	80 ,,
Ordinary foolscap	70 ,,
Ordinary newspaper	50-70 ,,
Deal wood	40-50 ,,
Yellow wall-paper	40 ,,
Blue paper	25 ,,
Dark brown paper	13 ,,
Chocolate paper	4 ,,
Black cloth	1·2 ,,
,, velvet	0·4 ,,

Some surfaces, such as finely divided magnesia, may under favourable circumstances reflect somewhat more light than white blotting-paper will do; but the reflecting power even in this case would probably not exceed 90 per cent. A low reflecting power may be associated with neutral properties as regards colour, *e.g.* when a substance is grey or black. But highly

[1] *Phil. Mag.*, vol. xxxv., 1893.

coloured materials, which pick out and reflect only a certain range of the visible spectrum, suppressing the remainder, have usually a low reflecting power. It should, however, be noted that the reflecting power of a coloured surface depends to some extent on the colour of the light illuminating it. For example, a red surface may appear black by the light of an illuminant which contains no red rays, such as the mercury-vapour lamp. Again, the reflecting power of some substances (such as rhodamine) is affected by the fact that it becomes fluorescent when illuminated by certain rays. Even the differences in hue of ordinary incandescent commercial illuminants may have a distinct effect on the reflecting power of surfaces, although it is only in the case of brightly coloured materials that the effect is very pronounced. Some comparisons of reflecting power by the light of the sky and an electric incandescent lamp have been carried out by Bell,[1]

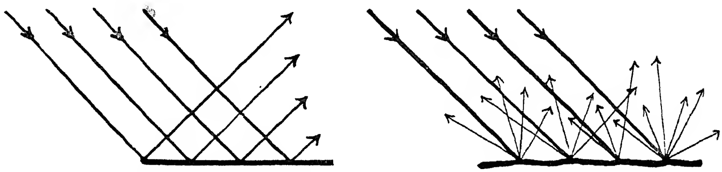


FIG. 79.—Illustrating difference between regular and diffused reflection.

and this method has been employed by Ritchie as a means of estimating the resemblance of various artificial illuminants and daylight.[2]

Determinations of the reflecting power of fabrics are usually complicated by the fact that they are more or less glossy. Consequently their apparent brightness varies with the angle at which they are viewed and the inclination of the rays of light illuminating them.[3] The accurate determination of reflecting power in these circumstances is a very complicated problem.

The consideration of glossy surfaces leads us to the distinction between regular and diffuse reflection. Diffused or scattered reflection takes place when rays of light strike an optically rough or matt surface consisting of small isolated particles. The rays are reflected in all directions, as shown in fig. 79, *b*. The

[1] *Trans. Am. Illum. Eng. Soc.*, Oct. 1907.

[2] *Illum. Eng.*, London, vol. v., 1912, p. 64.

[3] See some researches by F. H. Gilpin, *Trans. Am. Illum. Eng. Soc.*, Dec. 1910.

physics of this process are somewhat obscure, but it is probable that at least some of the light finds its way beneath the outer layer of material and then emerges again. In order to determine the reflecting power of such a surface, the sum of the light scattered in all directions must be considered.

In the case of regular reflection from smooth shiny surfaces each ray is returned in a given direction, such that the angles of incidence and reflection are equal, as shown in fig. 79, *a*. A certain amount of light is absorbed; otherwise the only change in the ray is that it proceeds, after reflection, in a new and definite direction. In the case of direct reflection one need only study the light reflected in any particular direction in order to find out the amount of light absorbed.

The following figures, given by Dr Louis Bell, show that the amount of light reflected from the best metal surfaces is not vastly different from that obtained from a pure matt white:—

Material.	Percentage of Light reflected.
Polished silver	93
,, gold	80
,, brass	75
,, copper	75
,, steel	60
Speculum metal	65

It may be added that the amount of light reflected from polished silver, or from good mirror glass, is sensibly the same throughout the visible spectrum.

There is some difficulty in securing an absolutely matt surface. A surface having this quality would be frequently desirable in photometry, but sufficiently satisfactory results can usually be obtained from such materials as dead white paper or cardboard, ground white celluloid, or pressed magnesia.

The diffusing and reflecting qualities of surfaces are of considerable importance in connection with the design of shades and reflectors. In many cases a mixture of the two varieties of reflection occurs. For example, the white surface of opal has a scattering effect, but the polished glaze upon it reflects light regularly. Another familiar example of a mixture of scattered and direct reflection is furnished by shiny "art" paper. The inconvenience of the glare from such paper due to the direct element has been referred to in Chapter V.

Surface Brightness and Intrinsic Brilliancy.—There are two chief methods of expressing the brightness of a surface

in what have been termed by Prof. Weber "primary" and "secondary" units.[1] In considering lighting installations the latter method is frequently preferable. For example, it has been stated that a room appears to be cheerfully lighted if the walls have a surface brightness of 0·3 foot-candle. By this is meant that the surface appears to the eye as bright as a white surface illuminated with 0·3 foot-candle would do. The unit of surface brightness is thus the foot-candle (or the lux), and may be defined as "the degree of surface brightness of a white matt surface of reflecting power 100 per cent., which receives an illumination of 1 foot-candle (or 1 lux).

It will be observed that if E is the illumination of a surface and ρ its absolute reflecting power, the surface brightness $\epsilon = E\rho$.

Reference has previously been made to the other method of denoting the brightness of objects, namely, in terms of their intrinsic brilliancy measured in intensity per unit radiating area (*e.g.*, c.p. per square inch). This method is most conveniently applied to very bright surfaces (mantles and filaments, illuminated lamp shades, etc.). It has been suggested as desirable to draw a distinction between intrinsic brilliancy and surface brightness, and to apply the former term to surfaces which actually generate light, and the latter term to illuminated surfaces which only become visible by reflected light. It is also convenient, on account of the size of the numbers involved, to use "candles per square inch" in the former case and "foot-candles" in the latter.

The connection between the surface brightness (ϵ), as defined above, and the intrinsic brilliancy (e) is a very simple one,[2] namely:—

$$\pi e = E\rho.$$

It may be noted that both quantities must be expressed in the same units, so that if foot-candles and candles per square inch are used the numerical relation is:—

$$\text{Surface brightness (foot-candles)} \quad = \rho E = \pi \times 144 \times e$$
$$= 450e \text{ (approx.)}.$$

The expression "specific luminous radiation" has been proposed to denote the flux of light per unit area emitted by a

[1] *Elektrot. Zeitschr.*, 26th Nov. 1908.

[2] A simple proof of this relation is given in Liebenthal's *Praktische Photometrie*, p. 34. See also *Illum. Eng.*, London, vol. vii., Sept. 1914, p. 440.

luminous surface. "Luminosity" is also sometimes used in the same sense as intrinsic brilliancy.

STANDARD PHOTOMETRIC SYMBOLS AND NOMENCLATURE.

At this stage it may be well to group together the chief quantities as defined above. The questions of appropriate symbols and nomenclature was first brought up at the International Electrical Congress of 1896, and Prof. Blondel, who was responsible for so much early pioneering work in this direction, has since suggested some additions to this list of symbols.[1]

In addition, the matter has been considered in detail by the photometric committee of the American Illuminating Engineering Society, and their last report contains a number of proposed definitions and new suggestions.[2]

This is a matter which is ripe for international action. Meantime the following table seems to embody the terms and symbols at present most generally employed :—

CHIEF QUANTITIES USED IN ILLUMINATING ENGINEERING.

Quantity.	Unit.	Equation and Symbols.
Intensity (Lichtstärke, Intensité lumineuse).	International Candle (Hefnerkerze).	I
Luminous flux (Lichtstrom, Flux lumineuse)	Lumen.	$\phi = I\omega = \frac{IS}{r^2}$
Illumination (Beleuchtung, Éclairement).	Foot-candle (lux).	$E = \frac{\phi}{S} = \frac{I}{r^2}$
Intrinsic brilliancy * (Flächenhelle, Éclat intrinsèque)	(Candles per sq. in., Candles per sq. cm.).	$e = \frac{I}{S}$
Output of light (Lichtabgabe, Lumière émise)	Lumen-hr. (Lumenstunde, Lumen-heure).	$Q = \phi T$

* Surface-brightness, ϵ in foot candles (or lux) is equivalent to $E\rho = \frac{I\rho}{r^2}$, where ρ is the coefficient of reflection of the surface illuminated.

These symbols and units are only given tentatively. The whole question is now being considered from an international standpoint, and was dealt with in a paper by Mr A. P. Trotter before the Illuminating Engineering Society (London) in 1914.[3]

[1] *Illum. Eng.*, London, vol. v., 1911, p. 205.
[2] *Trans. Am. Illum. Eng. Soc.*, vol. vii., No. 9, Dec. 1912, p. 727.
[3] *Illum. Eng.*, London, July 1914.

Measurements of Intensity.

Photometric measurements may be divided broadly into two classes, those which are concerned with the intensity of light sources (candle-power) and those relating to illumination. The photometry of light sources has become a more or less stereotyped process. The refinements necessary in the laboratory and the precautions necessary to secure accuracy have been ably discussed in Mr Trotter's well-known work.

The lamp to be tested and the standard may be set up at either end of a photometric bench, and the photometer, mounted on a sliding carriage, travels between the two. The photometer consists essentially of a specially designed screen so constructed as to enable us to observe when the two sides of it are equally bright, and the illumination received from the two lamps is the same. Then if I_1, I_2 be the intensities of the two sources, and their distances from the photometer screen giving equal illumination, we have, according to the inverse square law:—

$$\frac{I_1}{r^2} = \frac{I_2}{r_2^2} = E, \text{ whence } \frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}.$$

This method of moving the photometer is not invariably employed. Sometimes it is found desirable to keep the standard lamp and the photometer stationary, and to move only the lamp under test. For standard work the method of "double weighing" is always used. The procedure is as follows: The standard is placed at one end of the bench, and the photometer is fixed at a certain distance so that it receives a convenient illumination—say, 3 foot-candles. A "comparison lamp" (the intensity of which need not be known) is then introduced on the other side of the photometer, and its distance adjusted until the photometer is in balance. The comparison lamp and the photometer are then coupled rigidly together. Any lamps to be tested are substituted for the standard and compared against the comparison lamp, coupled, as explained, at a fixed distance from the photometer, the two moving as one unit. Or, if the positions of the comparison lamp and the photometer are fixed, balance may be obtained by moving the lamp to be tested. In this way the comparison is made with a fixed illumination, and, owing to the fact that the lamps are tested under exactly the same conditions as the standard, errors due to possible stray light, want of symmetry of the photometers, etc., tend to cancel out.

It will be observed that in either case the results are calculated on the basis of the inverse square law. In practice various devices are employed to lighten the calculations. When many lamps are tested under the same conditions, the scale of the photometric bench may be engraved direct in candle-power instead of in centimetres or inches, or tables and curves may be prepared, enabling the value of the candle-power corresponding to any divisions on the bench to be read off at once.

As stated above, measurements of intensity are almost always based on the inverse square law. Sometimes other methods are useful. For example, Krüss has advocated the use of dark glasses of known absorbing power for the testing of very powerful sources. Another device occasionally used is the rotating sector. The essential principle in this apparatus is the interposition of a rotating disc in the path of the rays of light. This disc is provided with an adjustible sliding shutter providing for a variable aperture comprising from 0 to 180 degrees of the complete revolution. The disc is driven sufficiently rapidly for the succession of bright and dark intervals to blend by persistence of vision, and the brightness of transmitted light is proportional to the percentage area of the disc exposed. A detailed investigation of this method, which appears to have been first used in this country by Mr H. F. Talbot and Sir William Abney, has been undertaken by Hyde.[1] This research established the scientific correctness of the principle, but in practice its application is not very convenient. Prof. J. R. Milne of Edinburgh has described a somewhat more elaborate apparatus involving the use of specially shaped rotating paddle-wheels.[2] Like many other devices for varying the intensity of light (crossed Nicols, liquids of graded opacity, etc.) such apparatus has been mainly confined to purely scientific researches.

A great deal might be written on the equipment of the photometric laboratory. It is sometimes assumed that the walls and ceilings and even the implements used should be painted a dead black, with a view to diminishing any possible errors due to stray light. But the inconvenience of working in such a room is obvious, and the opinion is gaining ground that for commercial work such extreme precautions are hardly necessary, providing the lamps on test and the photometer are judiciously screened.

It is, of course, essential that any other lamps used in the

[1] *Bull. Bureau of Standards*, Washington, U.S.A., No. 1, 1906.

[2] *Proc. Roy. Soc. Edinburgh*, 1910–1911, p. 656.

room with a view to providing illumination for taking notes, etc., should be well shaded; it is necessary to restrict the light to places where it is required, so as not to strike the photometer, and it is also highly desirable that the eyes of operators reading the photometer should not be dazzled by unshaded lamps.

PHOTOMETERS.

The practical success of photometry depends on the precision with which we can determine "equality of brightness." A photometer is merely a device for improving this precision.

The average man, if asked to examine in turn two widely separated illuminated surfaces, would find the utmost difficulty in comparing their brightness. In a photometer it is usual to bring the surfaces to be compared quite close together, and to aim at making the line of demarcation between them as fine as possible. Theoretically an object that has exactly the same colour and brightness as its surroundings becomes indistinguishable from them, but in practice it is difficult to reproduce this condition perfectly.

Many physiologists have attempted to ascertain the minimum percentage change in brightness perceptible to the eye, and Bouguer, whom Mr Trotter has justly styled "the father of photometry," devised a number of photometers quite early in the eighteenth century. One sometimes hears it laid down as a sort of physiological law, deduced from such early experiments, that the human eye cannot detect a change in brightness of more than 1 per cent. (or 2 per cent. as the case may be). But it must be remembered that these conclusions are merely the result of the apparatus employed. We have no reason to suppose that the limit of sensitiveness has been reached, and it is possible that in the future apparatus may be designed enabling us to detect much smaller changes in brightness than at present.

This fraction (sometimes known as Fechner's constant) is practically the same for all values of illumination likely to be used on the photometer screen in the laboratory. If the illumination on the photometer screen falls below one-tenth of a foot-candle there may be a diminution in sensitiveness. This appears to be true (for a given *physiological* brightness) irrespective of the colour of the light.[1]

[1] Dow, *Illum. Eng.*, London, vol. iii., 1910, p. 237; A. Broca, *Jr. de Physique*, 1894.

The general opinion seems to be that the most favourable illumination for the photometer screen lies between 1 and 5 foot-candles. In favourable circumstances (and when the two sources to be compared yield light of the same colour) the readings of an observer may be expected to agree within 1 per cent.; while the *mean* of a series of readings by experienced observers in the laboratory may be repeated within one-fifth or even one-tenth of a per cent.[1] This, of course, refers to accurate measurements in the laboratory; the precision obtainable in commercial photometry and with illumination photometers may naturally be less. In passing, a distinction should be drawn between the *general accuracy* of photometers (including all sources of light) and the accuracy with which readings on a

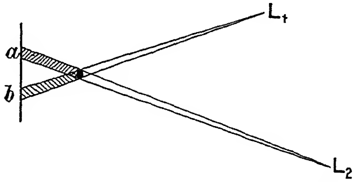


FIG. 80A.—Crude form of shadow photometer.

Shadows *a*, *b* are cast by a rod illuminated by the sources L_1, L_2. The arrangement shown is primitive, but by adjusting the position of the rod the shadowed regions *a*, *b* can be brought into juxtaposition (see fig. 80B).

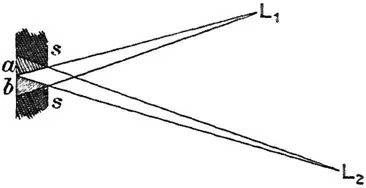


FIG. 80B.

In this arrangement the rod is replaced by a photoped carrying a screen *s*, *s*, in which there is a rectangular aperture. The position of this is adjusted until the shadows *a* and *b* just fail to overlap. They are conveniently cast on a translucent screen, and their brightness viewed from behind.

photometer can be repeated (which is merely a question of the sensitivenessof the instrument). Under favourable circumstances results can sometimes be repeated within one-fifth per cent. The general accuracy of commercial photometry has been estimated by Dr C. H. Sharp[2] to be 2 per cent., a result which is probably only approached in the best laboratories. For a very able discussion on this subject in photometry, the reader may be referred to the chapter "On Errors" in Mr Trotter's work.

It is not surprising that the experiences of various authorities with different types of photometers are apt to be somewhat inconsistent. In general an investigator favours the instrument with which he is most familiar. Moreover, the methods adopted of expressing the sensitiveness have not always been the same. As an instance of such researches, we may mention the experi-

[1] See some results presented by Mr C. C. Paterson, *Illum. Eng.*, London, vol. iii., 1910, p. 231.

[2] *Trans. Am. Inst. Elec. Engrs.*, vol. xix. p. 1493.

ments of Wild,[1] Kenelly,[2] and Barr and Phillips.[3] A series of researches was also carried out by the Netherlands Gas Commission in 1894. According to these experiments the Lummer-Brodhun and Bunsen (grease-spot) photometers rank among the most sensitive. For the comparison of lights of the same colour there are also certain flicker photometers, with which excellent results are said to have been obtained.

The various types of photometric screens in use have been so frequently described in well-known treatises on the subject that it hardly seems necessary to say much about them. Much of the earliest work in England was done with the shadow photometer invented by Count Rumford. In its most primitive form this consisted merely of a rod placed in front of a sheet of white paper, which was caused to throw two shadows on the

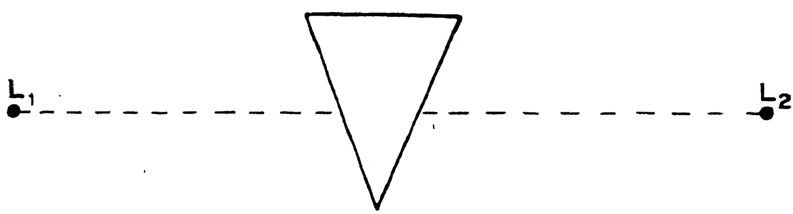


FIG. 81.—The simple Ritchie Wedge, the two inclined surfaces of which are illuminated respectively by L_1, L_2, the two sources to be compared.

lamp tested. The illumination from one of the sources was varied until the density of the two shadows appeared equal. The method was subsequently elaborated in the apparatus used by the Gas Referees. A slot, or series of slots, in a plate of metal replaced the rod, and their distance from the paper was adjusted so as to bring the edges of the shadows in exact contact. A piece of translucent paper was used so that the screen could conveniently be inspected from behind (see fig. 80B).

In the Rumford photometer the lamps under test are placed on the same side of the screen, but it was soon found that the method of placing them on either side of the screen was more convenient. In these circumstances it may be necessary to reverse the photometer so as to allow for any difference between the two sides of the screen, but in most cases the variation should not be large. One of the simplest photometers of this kind was the Ritchie Wedge, having two similar matt white sides

[1] *Electrician*, 8th Nov. 1907.

[2] Paper before the Nat. Elec. Light Assoc., Chicago, March 1908.

[3] *Electrician*, 9th March 1894.

exposed to the ten lamps under test, with as fine a line of division between them as possible. Plaster of Paris surfaces have occasionally been used. It is not easy to make the line of demarcation fine enough to secure high sensitiveness, and unless care is taken to place the wedge absolutely symmetrically with respect to the bench appreciable "angle errors" (*i.e.* errors arising from the fact that the rays of light do not strike the surface at the same inclination) may occur.[1] In order to eliminate such errors it is preferable for the rays of light to strike both sides of the screen approximately vertically.

The objection of angle errors may also be raised to other photometers, such as the Thompson-Starling, using inclined screens, unless the wedge is viewed from a fixed point.

The Ritchie Wedge photometer is now rarely used, but the wedge device has been introduced in some modern photometers, one of the most interesting of which is the Bechstein instrument.[2]

Another early type of instrument, usually known as the Joly photometer, utilised two translucent blocks of wax or semi-obscured glass, a fine metal sheet being usually insetted between the blocks to form a division, but the sensitiveness of this arrangement is not very great.

We now come to a photometer of early date which has persisted up to the present time, and indeed may still be described as one of the most sensitive available—the Bunsen or grease-spot photometer. The screen consists simply of a sheet of white paper, part of which is waxed and therefore becomes semi-translucent. The most general method is to make a greased annulus, the centre disc being left plain. The annulus then appears darker than the centre by reflected light, but brighter by transmitted light If one employs the "double-weighing" method, which eliminates want of symmetry in the photometric screen, it is only necessary to observe one side of the disc and to adjust the photometer until the centre spot just vanishes.

But it will be found that if one side of the disc is exactly in balance, the other side in general is not. When photometric balance is obtained by moving the instrument to and fro between the lamps compared, the correct method is therefore to adjust the position of the photometer so that the contrast between the

[1] See L. Wild, *Electrician*, vol. lvii. p. 59, 1908; also Trotter, *Illumination, its Distribution and Measurement*, p. 95.

[2] For a detailed description of this instrument see *Illum. Eng.*, London, vol. i., 1908, p. 498.

central disc and the annulus is the same on both sides of the screen. In practice inclined mirrors are placed on either side of the screen, enabling the observer to see both sides simultaneously (see fig. 82).

This "contrast" method should lead to a distinct gain in sensitiveness as compared with photometers of the "equality of brightness" type (*e.g.* Joly, Ritchie Wedge, etc.), and for this reason is preferable to the use of only one side of the disc. For, when the photometer is put slightly out of balance, so that the spot on one side becomes darker, an exactly similar change in the opposite direction takes place on the other side of the screen.

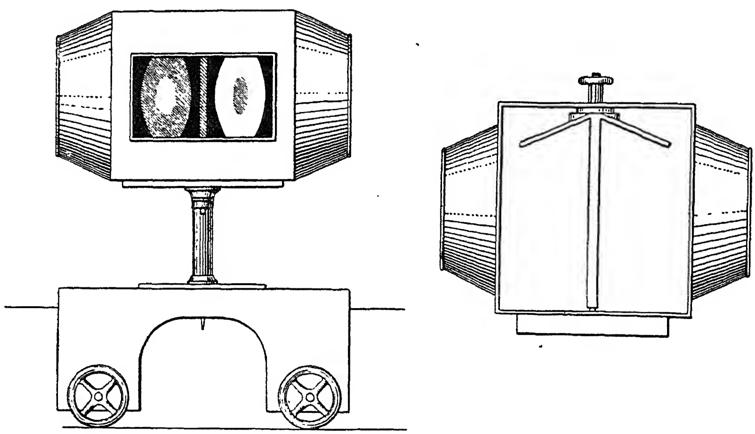


FIG. 82.—General view of Bunsen photometer.
(Reproduced from *Illumination, its Distribution and Measurement*, by A. P. Trotter.)

The eye, glancing successively at the two images, has therefore a *double change* by which to be guided.

The sensitiveness of a grease-spot screen depends in a great measure on the way the wax is applied. A modification of the greased spot is the Leeson disc, composed of three sheets of paper pressed together. The two outer sheets are thin and semi-transparent. The middle sheet is opaque, and a small disc is stamped out from the centre; a surprisingly fine line of division can thus be obtained.

The Lummer-Brodhun photometer has been described as a scientific grease spot, the paper disc being replaced by two accurately ground prisms in optical contact. The photometer has been so often described that we need hardly enter into the somewhat complicated details here. They are given fully

in Liebenthal's work,[1] and the photometer is also described by Mr. Trotter.[2]

Lummer and Brodhun studied the question of the desirable degree of contrast, and came to the conclusion that the maximum sensitiveness (0·22 per cent.) was obtained with an absorption by the thin glass plates of 3½ per cent.

For a more complete account of these details also readers may consult Liebenthal's work.[3] The line of division between the photometric surfaces is exceedingly fine, and the accuracy under favourable conditions is probably as great as that reached with any known photometer. But the fact that the field is observed through a telescope is considered a drawback by some observers, who prefer photometers of the grease-spot type, which can be inspected from a distance. Krüss has devised an arrangement comprising two telescopes and enabling binocular vision to be obtained.

It has been pointed out that the introduction of such sources of light as the flame arc, incandescent mantle, and mercury-vapour lamp has greatly added to the difficulties of photometry. A certain amount of practice is necessary, even when comparing lights of the same colour, to determine the exact point of balance of photometers which depend on the "equality of brightness" or "contrast" principle. When the two lights differ greatly in colour the difficulty becomes greater.

This circumstance has led to the revival of the flicker photometer, in which two surfaces, illuminated by the respective sources of light to be compared, are successively brought into the field of view; at a sufficiently rapid speed, the field of view then assumes a colour intermediate between that of the sources of light compared, but if the photometrical surfaces do not appear equally bright a curious throbbing or flickering effect is produced, and this only ceases when equal illumination of the two surfaces is secured. If the impressions succeed one another yet more rapidly, this flicker too ultimately ceases, and the sensitiveness of the photometer is correspondingly diminished. This question of the best speed for flicker photometers was discussed by one of the writers in 1907.[4]

1 *Praktische Photometrie*, p. 173.

2 *Illumination, its Distribution and Measurement*, p. 99.

3 *Praktische Photometrie*, pp. 180–187.

4 Dow, "The Speed of Flicker Photometers," *Electrician*, 1st and 8th Feb. 1907.

In using such an instrument we therefore select a speed which is sufficient to enable the colours to blend by persistence of vision, but not rapid enough to prevent the production of flicker due to the difference in brightness between the two surfaces. We then assume the position in which the flicker disappears, or is a minimum, to be the position in which the surfaces appear equally bright.

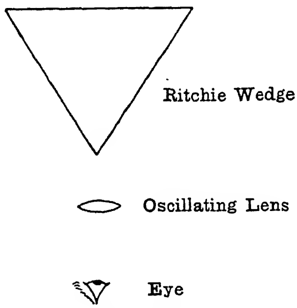


Fig. 83.—Rood flicker photometer.

Two sides of a Ritchie Wedge are illuminated by the sources to be tested. When the lens is caused to oscillate, the line of division between the illuminated surfaces appears to the eye to move rapidly to and fro, thus producing a flicker.

The first application of flicker to photometry is generally associated with the name of Prof. Ogdon N. Rood. The Rood form of photometer[1] consisted essentially of a Ritchie Wedge in the form of a plaster of Paris prism. The two sides of the prism were illuminated respectively by the two sources to be compared, and the sharp edge between the illuminated surfaces was viewed through an oscillating lens. The two surfaces, being by this movement of the lens alternately brought into the field of view, produced the impression of flicker.

The Bechstein flicker photometer utilises a modification of the Rood device.[2] A general view of the instrument is shown in fig. 84.

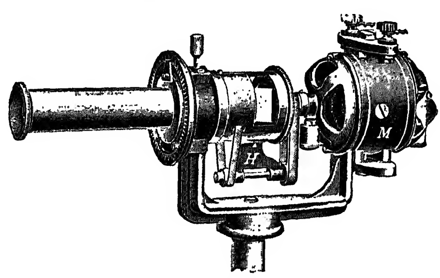


Fig. 84.—Bechstein flicker photometer (general appearance).

Following the work of Rood, Whitman[3] devised a form of photometer in which the two surfaces themselves are put in motion in such a way as to produce a flicker. In his original instrument one photometrical surface, inclined to the bench at a suitable angle, was illuminated by one of the sources to be compared. In front of this a cardboard disc, from which a circular

[1] *Am. Jour. of Science*, 1899, p. 194.

[2] *Zeitschr. für Instrumentenkunde*, vol. xxv., 1905, p. 45 ; see also *Illum. Eng.*, London, vol. i., 1908, p. 499.

[3] *Physical Review*, 1896, p. 241.

segment had been cut out, was placed, and was illuminated by the other source. As this disc was rotated the observer saw, in rapid succession, the disc itself and the surface behind it, and when these two surfaces were unequally illuminated a flicker was produced.

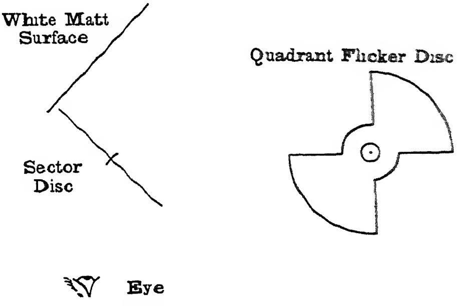


FIG. 85.—Whitman sector flicker photometer.

The white matt surface is illuminated by a source of light to the right, the sector disc by a source to the left. When this disc rotates the eye sees in rapid succession the surface of the disc and the surface behind it. When the illumination of the two surfaces is unequal a flicker results.

Another photometrical device used by Whitman[1] is shown in fig. 86. A truncated cone, ABCD, made of plaster of Paris was cut across diametrically at EF. The portion ABEF was then reversed and placed in the position shown. When the whole was rotated about the axis of the cone an observer saw in succession first the portion AB, illuminated by the light to the right, and then the portion CD, illuminated by the light to the left.

In fig. 87 are shown several types of flicker discs described by Krüss.[2] The first of these resembles the disc used in the well-known Simmance-Abady photometer.

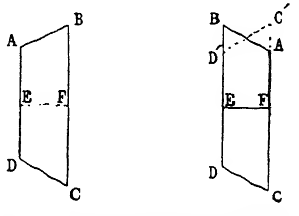


FIG. 86.—Showing the Whitman "truncated cone" flicker photometer.

The upper half of the cone ABEF is cut off and transposed, as shown in the right-hand figure.

When these pieces are rotated about a horizontal axis, the observer sees the boundary between the photometrical surfaces continually cross and recross the field of view. This change occurs twice in every revolution in the case of No. I., four times in every revolution in the case of No. II., and six times in the case of No. III.

More recently Krüss has devised a means by which the principle of flicker can be combined with the use of the Lummer-Brodhun photometer head.

Wild has devised a very simple form of flicker photometer, in which the expedient is adopted of rotating a grease-spot

[1] *Science*, 1898, p. 11.

[2] *Physikalische Zeitschr.*, 5, pp. 65–67, 1903.

disc. The disc is cut out of ordinary white blotting-paper, about half of its surface being greased and half plain. This disc is merely rotated about its centre by means of a small electric motor, and a portion of the upper part of the disc is viewed through a telescope. In this way the possibility of angle errors is very much reduced, and under the very best conditions the sensitiveness is said to rival that of the Lummer-Brodhun photometer. Wild has shown how binocular vision can be obtained with this instrument and the contrast principle applied.[1]

The advantage ascribed to flicker photometers lies in the fact that an unpractised observer usually finds it very difficult

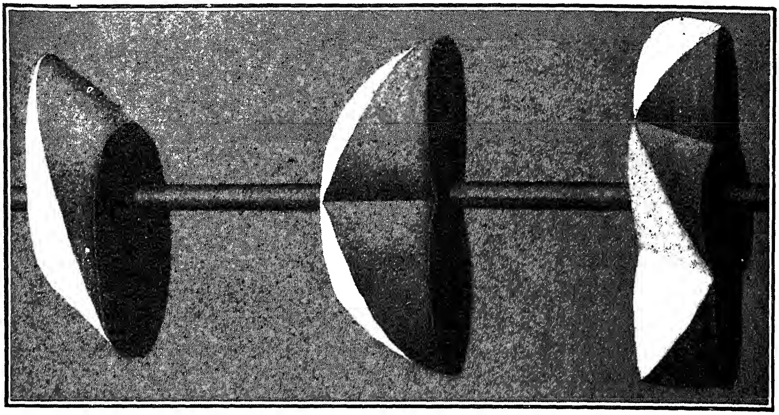


FIG. 87.—Types of flicker discs, Nos. I, II., III.
(Produce respectively two, four, and six reversals per revolution.)

to distinguish small differences of light and shade when the sources of light to be compared differ greatly. On the other hand, it is urged that but little practice is needed to enable an observer to decide whether or no a flicker is visible through the telescope of a photometer, and to set the photometer so that the field appears flickerless.

As regards the correctness or otherwise of the flicker principle in colour work we shall have something to say in the next section.

THE PROBLEM OF COLOUR PHOTOMETRY.

From what has been said above it will be gathered that we can now compare the illuminating power of sources of light with

[1] See *Illum. Eng.*, London, vol. i., 1908, p. 825.

very tolerable accuracy. But this accuracy, which is probably sufficient for most practical purposes, is only attainable when the lights compared are similar in colour. When two illuminants yield lights of widely different colour their comparison becomes difficult. A trained ear could no doubt judge with fair exactitude which is the louder of two adjacent notes struck on the piano; but it is much more difficult to compare the loudness of a shrill whistle with that of a beaten drum. Doubtless one would not find much difficulty in selecting two roses of the same class having an equally strong scent; but would it be possible, by any system, to compare the scent from a rose with the odour of paraffin?

Similarly, the determination when two adjacent surfaces of widely different colour *appear* equally bright is difficult to many people, although trained observers profess to be able to form a consistent judgment.

A distinction may, at the outset, be drawn between the problems involved in the comparison of commercial illuminants and those which confront us when we attempt to judge the brightness of pure spectrum colours. The differences in tint met with in illuminants yielding continuous spectra do not give rise to serious difficulties. Most people find no very great obstacle to comparing an incandescent mantle with an Argand burner, a metal-filament lamp with a carbon-filament one, or even a white arc lamp with an electric glow-lamp.

In the case of standard work even these comparatively slight differences in colour may be of some consequence. A device known as the "cascade" method is employed at the National Physical Laboratory. A series of standards of progressively varied efficiency has been prepared, and the difference in colour between each successive pair is too slight to cause trouble. Consequently each standard can be accurately compared with any other, although the difference in colour of the first and last may be considerable. In testing other lamps a standard of any desired colour within the prescribed limits may then be used. In America a somewhat similar method, based on the use of suitably tinted glasses, has been adopted by the Bureau of Standards, and the authors understand that it was already in use many years ago at the Reichsanstalt.

More recently illuminants have been introduced (such as the flame arc, the Moore tube, the neon tube, and the mercury-vapour lamp) which yield line-spectra and differ widely in colour.

It is undoubtedly a difficult problem to compare the neon tube, giving only lines in the orange and red, with the mercury-vapour lamp, the rays of which are concentrated in the yellow, green, and blue-violet. Some experiences in the photometry of these lamps were recently described by Dr Broca and MM. Jouast and Laporte. Divergences in the results of different observers of as much as 100 per cent. were recorded.[1] The difficulties become extreme when one attempts to compare pure spectrum colours; and the exact shape of "luminosity curves" for the spectrum can therefore only be determined approximately; this, of course, does not apply to spectrophotometric measurements in which the spectra are matched colour by colour, but only to those in which heterochromatic comparisons are made.

These errors also occur, although usually in a less inconvenient form, in the case of investigations on coloured fabrics, wall-papers, etc.

The fundamental physiological difficulties of colour photometry were touched on in Chapter VI. (Colour and the Eye). It has been pointed out that the condition of the human eye with respect to the perception of coloured light is quite different in a feeble light from what it is when the illumination is high. Whatever be the physiological explanation—whether based on the struggle between the "rods" and "cones" or the changes in the visual purple—the dark-adapted eye is singularly insensitive to red, and highly sensitive to green and blue rays. In a feeble light, as we have seen, red objects tend to appear jet-black.

Naturally these effects reveal themselves directly the attempt is made to compare illuminants differing much in colour. Very marked discrepancies between the results at high and low illuminations were recorded in the experiments by Broca, Jouast, and Laporte on neon and mercury-vapour lamps, referred to above. One of the authors, in a series of experiments on lamps screened with red and green glasses, has shown how such measurements are also affected by the size of the photometric surfaces, the distance of the eye of the observer, and the angle of inclination at which they are seen.[2] We must remember too that the sources of light we are attempting to compare would certainly be used to illuminate surfaces very much greater than

[1] "Quelques Difficultés de la Photométrie des sources luminescentes industriels," *Bull. Soc. Int. des Électriciens*, Feb. 1913.

[2] Dow, "Colour Phenomena in Photometry," *Phil. Mag.*, Aug. 1906.

those existing in the photometer, and measurements in the laboratory may therefore fail to represent accurately the illuminating power of a source under practical conditions.

It is difficult to see how one can evade these phenomena completely. Even if one could contrive a method of measurement independent of them, we should *ipso facto* fail in our purpose, since the results would not bear an exact relation to experiences in practice. One general rule may be suggested—the illumination of the photometer screen should be about the same as that which the lamps will be expected to furnish in practice. Experience has shown that at fairly high illuminations (say, above 1 foot-candle) these colour effects have a comparatively small influence, since the eye is in a more or less "saturated" condition. It is really only when the illumination is low (as in street lighting) and in the case of illuminants having exceptional spectra that practical difficulties arise.

For this reason photometers of the "extinction" class, the action of which depends on dimming the light tested until some small object can only just be perceived, should be used with caution. For the eye is then in an abnormal condition, and the portion of the spectrum that is influential may not be that which is most effective at ordinary illuminations.

It has been shown that a number of early experiments on acuteness of vision were misinterpreted owing to disregard of this point. Some observers found that acuteness of vision was greatest in the yellow (near $\lambda = 0{\cdot}58\mu$), others that it reached a maximum in the green (near $\lambda = 0{\cdot}52\mu$). In reality the conclusion reached appears to have been due simply to the order of illumination at which these experiments were carried out.

It may be of interest to mention a few of the methods suggested with a view to minimising these difficulties. Readers may be referred to the various treatises mentioned at the commencement of this chapter, and particularly to the section of Uppenborn's work dealing with this subject, which contains an excellent bibliography.[1]

These devices fall into several distinct classes. There are those based on the use of coloured screens. Macé de Lepinay[2] proposed to view the photometric surface first through a red screen and then through a green screen, and he gave a formula for which the true relation between the illuminants tested could

[1] *Lehrbuch der Photometrie*, pp. 284–310.

[2] *Comptes Rendus*, vol. xcvii. pp. 1428, 1883.

be calculated in terms of the readings obtained. The same method has been pursued by Weber,[1] Schumann,[2] and others. But the method, besides being somewhat tedious and inconvenient, is clearly inapplicable to sources having discontinuous spectra—particularly to such a source as the mercury-vapour lamp, which contains no red rays. A more scientific method was that due to Crova,[3] who used a yellow screen. Theoretically this was supposed to absorb all rays except that at $0{\cdot}582\mu$, and Crova considered that the comparison of the intensity at this point in the spectrum gave a true measure of the relative integral intensities. Practically a solution confining the radiation to a narrow region of the spectrum in this neighbourhood is found to absorb a great deal of light. Moreover, the principle involved, like that of Macé de Lepinay, would only apply to continuous spectra, and cannot be used in the really difficult colour comparisons.

Other methods are based on the principle of acuteness of vision. Weber (*loc. cit.*) many years ago proposed to illuminate black and white patterns, such as concentric circles composed of lines of progressively diminishing thickness; and Dr Fleming devised "discrimination photometers," in which the illuminants compared were made to illuminate a series of fine dots. The idea was to judge one's position of balance not by equality of illumination but by "equal distinctness." But in practice it may be questioned whether this practice assists one's judgment to any great extent; in addition, the basis of the method appears to be theoretically unsound, and, for the reasons explained in Chapter V., it may prove actually misleading.

We come next to the flicker photometer, the theory of which has recently been studied by Dow,[4] and many other observers. A recent series of contributions by Ives in the *Philosophical Magazine* on this subject, and also on the general principles of colour photometry, is of special interest.[5]

It has been claimed as an advantage that the flicker photometer is independent of colour, inasmuch as colour-blind observers

[1] *Elektro. Zeitschr.*, 5, p. 166, 1884.

[2] *Ibid.*, 5, p. 220, 1884.

[3] *Comptes Rendus*, xciii. p. 512; xcix. p. 1067.

[4] "Colour Phenomena in Photometry," *Phil. Mag.*, Aug. 1906; "Physiological Principles underlying the Flicker Photometer," *Phil. Mag.*, Jan. 1910.

[5] "The Photometry of Lights of Different Colours," *Phil. Mag.*, July, Sept., and Nov. 1912

obtain the same results with it as do people with ordinary vision. Were this a fact it would seem a doubtful recommendation from the theoretical standpoint, but researches made at the Reichsanstalt and elsewhere by no means bear out this view.[1] On the other hand, many colour phenomena do seem to be less marked with flicker instruments than they are with those of the equality of brightness type. Ives indeed, and also Luckiesh,[2] finds that the Purkinje effect is actually *reversed* with the flicker instrument. It appears to be now generally agreed that at ordinary illuminations, and with sources having continuous spectra, both types of photometers give substantially the same results. At low illuminations this may not be so, but it remains to be determined which form of instrument gives the more exact measure of practical illuminating value.

The problem is complicated by the peculiarities in vision of different observers. Ives, in the researches mentioned above, includes tests of a number of people from which he deduces the luminosity curve for the normal eye, and it is suggested that this might be assumed in researches on colour photometry.

Finally, there have been several suggested standards of light based on the measurement of radiation, which may fitly be considered in relation to the problems discussed above. Drysdale proposed a primary standard using, not incandescent platinum, but a black body maintained at a fixed temperature.[3] Houstoun[4] and Strache have suggested that by the use of suitable colour solutions, or by optical means, it might be possible to isolate the visible from the total radiation of an incandescent surface and to absorb the various rays in such proportions as to give a luminosity curve identical with that of the eye, thus constituting white light. Steinmetz proposed to select energy of certain wave-length in the red, green, and blue, and to combine these elements in suitable proportions to produce a white light. It might be possible to measure the radiation of these definite single wave-lengths with exactitude and to

[1] *Gas World*, 11th April 1908; see also F. L. Tufts, *Am. Jr. of Science*, 22, p. 531, Dec. 1906.

[2] "The Purkinje Effect with Flicker and Equality of Brightness Photometers," *Elec. World*, 22nd March 1913.

[3] Discussion before the Physical Soc. of London, June 1909, *Illum. Eng.*, London, vol. ii., 1909, p. 144.

[4] *Proc. Roy. Soc. London*, June 1911.

avoid the experimental difficulties involved in measuring the radiation from continuous spectra.

Ives has suggested that it might be possible by suitable screens to isolate the green mercury line (which is very near the point in the spectrum where the maximum sensitiveness of the eye is located) and to measure the radiation of this single wave-length by physical means.[1]

All these methods are apparently based on the idea of defining a standard of light in terms of physical measurement and avoiding the perplexities caused by the physiological peculiarities of the eye. But it would seem that the experimental difficulties are considerable, and that even the physiological difficulties are postponed only and not avoided.

Physical Methods in Photometry.

The idea of using so-called physical methods in photometry (*i.e.* the direct action of light on some material, independent of the eye) has a certain fascination. One would appreciate an instrument which, if pointed at a lamp, would straightway register its illuminating value on a dial without its being necessary to introduce the complexities of the human eye.

But none of these chemical and physical methods respond to radiant energy in exactly the same manner as the eye. The thermopile would be mainly influenced by the heat rays of an illuminant; actinometers and photographic paper are in general affected most by the ultra-violet. At present, therefore, it hardly seems possible to use such an apparatus for absolute measurements and for the comparison of different illuminants. But it *is* conceivable that it might be useful for purely relative work, where no comparison is attempted between sources having widely different spectra—for example, in making tests of daylight, or in obtaining polar curves of light distribution.

The first of such methods that naturally occurs to one is the use of photography. Photographic paper has often been so used, and is sometimes employed in connection with ancient light cases even at the present time. But photography cannot as a rule compete with ordinary photometry for convenience and accuracy, and its use is practically restricted to spectrophotometric researches (such as the investigations of Ives and

[1] "Energy Standards of Luminous Intensity," *Trans. Am. Illum. Eng. Soc.*, April 1911 and Oct. 1912.

Coblentz on the spectrum of the fire distribution of brightness in the spectrum of the fire-fly). Recently Ives and Luckiesh have devised a photographic method of determining polar curves.[1] A strip of light-sensitive paper is wound in the form of a cylinder, the light to be tested being at its centre. Under suitable conditions of exposure and development the darkening of the paper will be proportional to the intensity of the light striking it at that point. One advantage claimed for this method is that it acts as a "ballistic photometer," automatically recording the mean of the readings during a given period, and being therefore specially applicable to the photometry of sources which are inclined to flicker.

Another physical apparatus that has sometimes figured in photometry is the thermopile. A thermopile with blackened surface is sensitive to all forms of radiant energy, and does not discriminate between the visible and non-visible rays. It could not therefore be applied for comparing different illuminants in the spectra of which visible and invisible energy exists in variable proportions. Felton and Brady, in a paper read at the annual convention of the Illuminating Engineering Society in the United States in 1910, showed some polar curves of light distribution obtained by this means. The thermopile appeared to give fair results for electric incandescent lamps, and the method would presumably be expeditious. But in the case of gas lamps the curves were distorted by the effects of conduction and convection of heat from the burner. Voege has likewise used the thermopile for this purpose, and he has also shown that it can be conveniently applied to record the variations in light of unsteady sources.[2] There certainly seems to be a need for some standard method of comparing the steadiness of different illuminants.

Another appliance which has often attracted interest for photometric work is the selenium cell, the resistance of which changes when it is exposed to light. A photometer based on this principle was devised by Torda some years ago.[3] The experimental difficulties connected with such cells are at present considerable. Special care is necessary in the preparation of selenium in order to avoid the effect of the inertia of the material. Torda hoped to overcome this difficulty by the use of

[1] *Elec. World*, 20th July 1912.
[2] *Elektrot. Zeitschr.*, 16th Jan. 1908.
[3] *Electrician*, 13th April 1906.

a clockwork shutter, which automatically cut off the light from the cell after it had been exposed for a certain period. The sensitiveness of the cell to light of different colours depends on the way in which the selenium is prepared. Prof. Ruhmer of Berlin makes two forms, which are respectively most sensitive in the red and the green regions of the spectrum. He is also reported to have obtained cells whose maximum sensitiveness lies in the ultra-violet. One curious circumstance related by Pfund [1] is that the selenium cell is subject to a phenomenon analogous with the Purkinje effect, the maximum sensitiveness of some cells being in the green at low illuminations and in the orange-red when the illumination is high. This characteristic, coupled with the fact that the ordinary selenium cell, unlike the thermopile and the photographic methods, does at least have its maximum sensitiveness within the visible spectrum, suggests that it might be possible in the future to prepare cells having a curve of sensitiveness substantially the same as that of the normal eye. In this case it might be applied for ordinary photometric work. But even should we succeed in evolving a successful physical photometer by this or other means, it would seem to be essential that its use should be periodically checked by appeal to the eye and by comparison with ordinary photometric methods.

The use of selenium cells has been practically confined to relative measurements, such as the recording of daylight variations in school-rooms and the study of the fluctuations in light during an eclipse.

Ban and Philips,[2] Presser,[3] and others have also suggested devices to enable the cell to be used in the photometric laboratory, but up to the present time very little work has been done in this way.

More recently an interesting departure has been made by Richtmyer [4] and Voege [5] in applying alkali metal cells of the type devised by Elster and Geitel to photometry. Such cells have several distinct advantages. There is said to be little "inertia," the relation between galvanometer reading illumin-

[1] *Physical Review*, vol. xxxiv., May 1912.

[2] *Electrician*, vol. xxxii. p. 525.

[3] *Elektrot. Zeitschr.*, 1907, p. 510.

[4] *Trans. Illum. Eng. Soc. U.S.A.*, vol. viii., 1913, p. 459.

[5] Paper read before the German Illuminating Engineering Society, March 28, 1914: *Illum. Eng.*, London, June 1914, p. 295.

ation is linear over a wide range, and the maximum sensitiveness is located in the visible spectrum. Voege has found that such cells, equipped with a suitable light filter, answer well for testing lamps of the same class, and are very constant. In general their use is only proposed for relative work. The current to be measured (10^{-9} ampères) is small but not very inconvenient in the laboratory. On the whole, experience with these cells is favourable, but it is too early yet to appraise their value in practical photometry.

THE DISTRIBUTION OF LIGHT FROM ILLUMINANTS.

Let us now pass on to another phase of photometry—the study of the distribution of light from illuminants. In Chapters II. and III. quite a number of diagrams were given showing how much modern illuminants differ in this respect. An ordinary direct-current lamp with vertical carbons gives its maximum light at an angle of about 50 degrees in the lower hemisphere, but a shadow will be cast by the lower carbons and there will be very little light immediately under the lamp. The intensity in a horizontal direction will also be small. The burner below an upright gas mantle also throws a deep shadow, but the maximum intensity in this case is horizontal. The carbon-filament electric lamp gives about 40 per cent. of its horizontal intensity immediately under the lamp; and the metallic filament, arranged as a series of vertical elements, yields even less. Many inverted mantles, being approximately spherical in shape, give practically their maximum light in every direction in the lower hemisphere, but the burner intercepts much of the light above the lamp.

In what has been said above we have assumed that the source is not provided with a globe or reflector. It is possible by using an appropriate reflector to modify the distribution of light very considerably. For example, by merely placing a focussing type Holophane reflector over a metal-filament lamp we concentrate by far the greater part of the light in the lower hemisphere, and the greatest intensity is then obtained immediately below the lamp. As another illustration of the effect of a slight change in the shape of the reflector, take the distribution curves of the Sugg and Grätzin gas lamps shown in figs. 20 and 21 in Chapter II. In the former case the maximum is vertically downward, in the latter the greatest intensity is reached in a direction slightly below the horizontal.

In practice we generally require a lighting unit to give its greatest intensity in a downward direction, so as to illuminate a desk, table, or bench, etc. But there are also occasions when we aim at illuminating vertical surfaces, such as blackboards, placards, etc., and in these cases a strong horizontal component is necessary. Again, in the indirect system of lighting, we deliberately throw most of the light upwards on to a white ceiling. It is therefore a matter of considerable importance to know how the light from any unit is distributed, and there are many manufacturers who now make a practice of giving information on this point. Without a knowledge of the intensities in various directions we cannot perfectly compare the capacities of modern illuminants. To measure only the horizontal candle-power, or to state only the candle-power in the direction of maximum intensity, and to ignore the distribution of light in all other directions, would often lead to very misleading conclusions. In order to represent the distribution of light in space, we use what is termed a "polar curve of light distribution." A number of diagrams have already been given. Such diagrams are usually drawn to polar co-ordinates. The centre of the diagram corresponds with the centre of radiation of the source of light, and the lines radiating outwards in all directions may be taken to represent the direction of the light-rays emitted by the lamp. The concentric circles serve as a scale of candle-power, and the diagram is built up by measuring off along each line a length proportional to the candle-power in that direction, and drawing a curve through the points obtained.

The determination of such curves in the laboratory is usually a somewhat intricate and tedious process. The method employed varies according to the dimensions of the unit to be tested. As a rule the lamp cannot conveniently be tilted, and it is therefore usual to rotate round it a mirror or mirrors placed in such a way that the ray of light in each direction is successively directed along the photometric bench. But it is possible to mount small electric glow-lamps in a holder capable of motion in a vertical plane, and, by tilting the source itself, to avoid the use of mirrors.

For a description of some modern devices used with very large sources, readers may be referred to a paper by G. H. Stickney and S. L. E. Rose read at the Fifth Annual Convention of the American Illuminating Engineering Society in 1911. Also to the lecture on photometry delivered by Dr Sharp at the

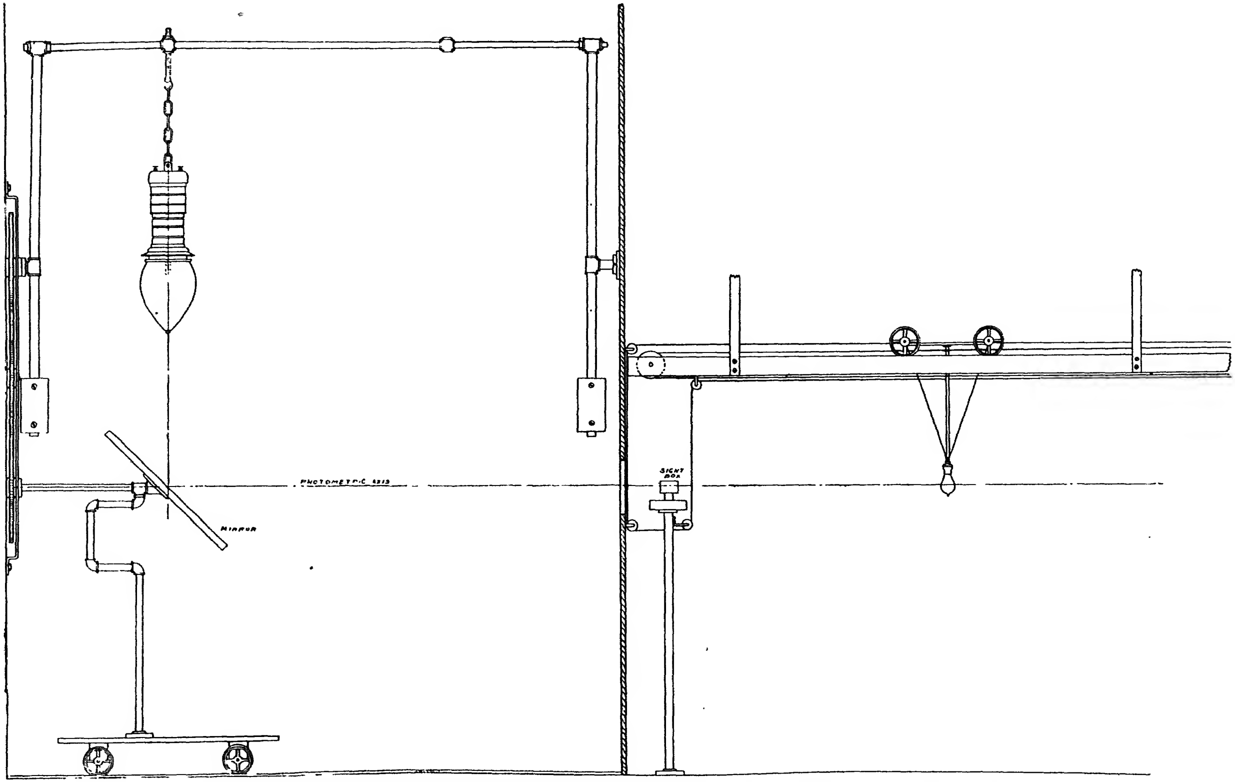


Fig. 88.—Showing arrangements for determining the light distribution from arc lamps in the laboratory of the General Electric Co. of America (Stickney and Rose, *Trans. Amer. Illum. Eng. Soc.*, vol. vi., 1911).

The lamp is suspended in a separate chamber, and its rays are reflected from an inclined mirror and pass through an aperture on to the sight-box of the photometer, as shown. Photometric balance is adjusted by moving the comparison incandescent lamp.

Johns Hopkins University, Baltimore, in October of the same year.

Fig. 88 shows diagrammatically a very usual arrangement. The lamp to be tested is suspended, preferably in a section of the laboratory partitioned off from the rest of the room, so that the powerful sources may be completely screened from the eyes of the observer working the photometer. The ray of light is reflected off a 45 degrees mirror through an aperture along the photometric bench. The mirror is rotated successively into positions equivalent to intervals of about 10 degrees, and the position of the arc lamp being adjusted in each case so that the reflected ray still passes along the line of the photometric bench. It will be observed that the angle of incidence with the mirror is always the same, so that the absorption is constant. The

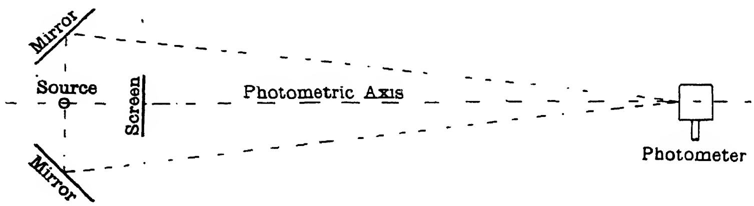


FIG. 89.—Showing method of investigating the light distribution of a source by aid of two symmetrically placed inclined mirrors.

These two mirrors reflect the rays on to the photometer screen (which is kept stationary), while the direct rays are screened.

coefficient of absorption of mirrors used in this way is usually determined by a separate test on a lamp of known candle-power; for a good silvered mirror it should be practically the same for all colours in the visible spectrum. The lamp tested should travel on an arc or a circle struck about the centre of the mirror. The continual adjustment of the position of the arc lamp on test is rather a drawback to this method, and gearing is usually fitted up to make the adjustment as expeditious as possible.

An improvement on this method is the use of two movable inclined mirrors symmetrically placed so as to reflect a ray at the same angle on either side of the lamp. The light from both mirrors strikes the photometer, and the mean of the readings in both hemispheres is automatically recorded. In the case of unsteady flickering sources this is a distinct advantage This method is now very widely adopted. Fig. 90 shows the application of the method in the laboratory of the General Electric Co. of America. An advantage is that the lamp is kept stationary.

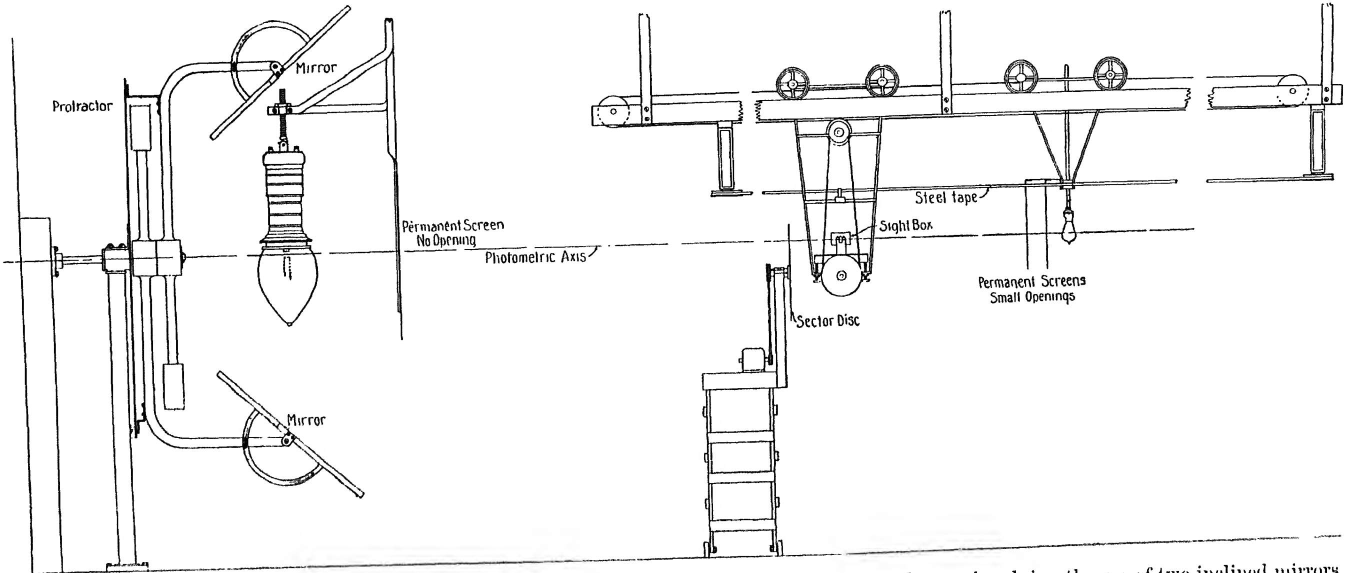


FIG. 90.—A somewhat more elaborate method of determining the distribution of light from arc lamps, involving the use of two inclined mirrors placed symmetrically on either side of the source (Stickney and Rose, *Trans. Am. Illum. Eng. Soc.*, vol. vi., 1911.)

The reflected ray passes through the adjustable reflector disc to the sight-box of the photometer. Photometric balance can be secured by moving either photometer or lamp, or by altering the aperture in the sector, so that there is a wide range of adjustment.

Another form of rotating mirror arrangement which also eliminates any necessity for moving the lamp during the test is that shown in fig. 91, due to Franz Schmidt and Haensch, and used in the Holophane laboratory in London. The arrangement is convenient but is somewhat bulky, and therefore requires a fairly large laboratory. It is best suited to fairly powerful sources. The double reflection means that the lamp tested is virtually removed to a considerable distance from the photometer. Consequently, when units of moderate candle-power are tested, the illumination on the photometer screen is apt to be somewhat low.

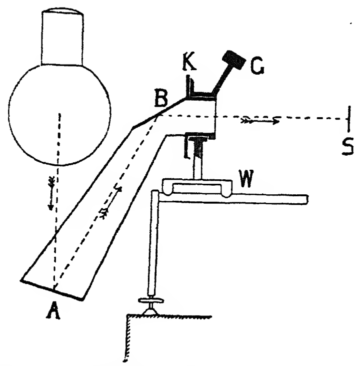


FIG. 91.—A double rotating mirror arrangement for investigating the light distribution from large sources (Franz Schmidt and Haensch).

The ray of light strikes the mirror at A, whence it is reflected to the second mirror at B, and thence along the line of the photometric bench to the screen S of the photometer. G is a counterpoise arrangement enabling the two mirrors, which are rigidly coupled together, to be easily rotated.

There is also a group of methods of determining polar curves in which the use of mirrors is dispensed with. For example,

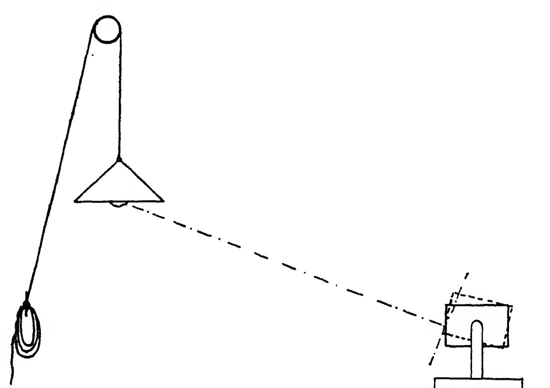


FIG. 92.—A method of obtaining polar curves by inclining the photometer screen.

If the light reaches the screen at an angle θ to the horizontal, the screen will be rotated through an angle of $\theta/2$.

the lamp may be suspended in line with the photometer bench and merely raised and lowered. The photometer is preferably kept stationary, photometric balance being obtained by moving

the comparison lamp. The photometer is usually equipped with a scale of angles and a lens-centring arrangement, and can be rotated about a horizontal axis. The operation is as follows: The photometer is set at the angle (θ, say) corresponding with the ray to be measured. The height of the lamp is then adjusted until an image of it is formed by a lens over two cross lines marked in front of the photometer screen. But if the test were carried out with the photometer in its present position, an error would be introduced by the fact that the rays from the lamp tested and the comparison lamp do not strike the photometer screen at the same angle. To correct this, the photometer is rotated back through an angle $\theta/2$. In a form of photometer used by the South Metropolitan Gas Co., the lamp is suspended on a movable arm geared to the photometer in such a way that this process is performed automatically. The change in inclination is then the same in both cases and cancels out. This method has the advantage of dispensing with a mirror, but considerable care must be taken in setting the photometer in order to avoid angle errors. Another difficulty is that an unusually high room would be needed for rays near the vertical to be tested, and it would also be inconvenient for many readings in the upper hemisphere to be determined. Moreover, the distance between the lamp tested and the photometer is a variable quantity, which is often not desirable in work of this kind.

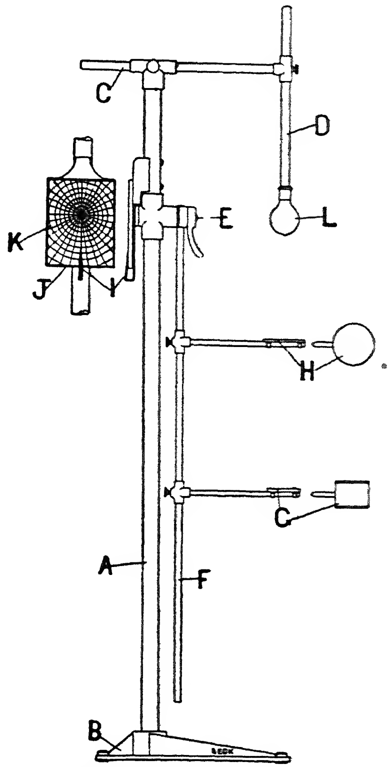


FIG. 93.—Holophane polar curve apparatus.

The white screen (G) attached to the arm (F) can be revolved round the source (L), whose position can be varied by means of the adjustable arms (C and D). The pointer (I) traces out on the chart (K) the angles through which the arm is moved, and the polar curve can be traced out while the experiment is in progress. The screen (H) can be used to cut off the direct light from the source tested, and thus to estimate what error (if any) is caused by stray light. This enables the apparatus to be used in a room with fairly light walls.

There is one other method of determining polar curves that may be mentioned. It has been described by Dr C. H. Sharp in the United States [1] and by Dow and Mackinney in this country [2] It has some distinct advantages but also some limitations.

According to this method, the mirror is replaced by a matt white surface, which is rotated round the source and at a fixed distance from it. The surface brightness of this surface is observed through an illumination photometer, and is proportional to the candle-power at the respective angles. The method is expeditious, but the length of arm carrying the white test surface is necessarily restricted. This may necessitate the introduction of mirrors when testing sources which depart widely from the inverse square law. In the arrangement proposed by Dow and Mackinney, the rotating arm carries a pointer tracing out the angles on a sheet of polar paper and enabling the distribution curve to be plotted out while the experiment is actually in progress.

It has been remarked as desirable that in work of this kind the distance between the photometer and the source tested should be kept constant. This precaution is needful in order to eliminate possible errors due to non-compliance with the inverse square law. Such errors may arise when the source is equipped with very large diffusing globes or highly focussing reflectors. Many such reflectors act somewhat like a search-light. When there is any doubt on this point the distance at which the test is made should preferably be stated. Another point to be noted is that all these methods assumed that the distribution of light is symmetrical about a vertical axis. This is generally the case, the chief exceptions being sources equipped with parabolic reflectors and intended for the illumination of vertical surfaces. In such cases the curve is usually determined in the plane of symmetry of the reflector, and this is doubtless the most useful plane to take. But the fact that the results only refer to a particular plane should be borne in mind in calculating mean spherical candle-power.

The Determination of Mean Spherical Candle-power.

The examples quoted on page 237 show how necessary it is, when comparing illuminants, to state the particular direction in

[1] Lectures on Illuminating Engineering before the Johns Hopkins University, Baltimore, Oct. 1910, vol. i. p. 423.

[2] Paper read before the Optical Convention in London, June 1912.

which the candle-power of sources has been determined. On the Continent it has become customary to indicate this by a special symbol, $I\alpha$, indicating the intensity at an angle α, and this method might, with advantage, be more widely followed in this country.

The definition of the mean spherical candle-power has already been given, namely, the intensity which a source would possess if it gave out the same total flux of light, but evenly in all directions. It is denoted by the symbol I_0. In the same way, by the mean hemispherical c.p. we mean the candle-power which a source would yield in the (upper or lower) hemisphere, if the light were uniformly distributed. If we denote the mean upper hemispherical candle-power by $I_{\frown}$ and the mean lower hemispherical candle-power by $I_{\smile}$, it is evident that:

$$I_0 = \frac{I'_{\frown} + I_{\smile}}{2}.$$

The mean spherical candle-power can be readily calculated from the polar curve of light distribution of a source. In fact it is usually obtained in this way. It is a common mistake for people to suppose that the mean spherical candle-power is obtained merely by taking the mean of the intensities in one plane as shown in the polar curve. This is not correct A special calculation is necessary, the general expression for the mean spherical candle-power being, $\frac{1}{2}\int_{\theta=0}^{\theta=\pi} I_\theta \sin\theta \, d\theta$.[1]

Theoretically, therefore, the way to obtain the mean spherical candle-power from the polar curve is to divide it into an infinite number of small sections, multiply the intensity at each point by $\sin\theta$, add up and divide by 2. Practically a sufficiently accurate result can be obtained by dividing the hemisphere into zones of 5° or even 10°. The corresponding values of $\sin\theta$ are calculated once and for all, and it is customary in laboratories where much work of this kind is done to have the values printed at the side of each sheet of polar curve paper in tabular form, the corresponding values of the intensity are read off and entered and multiplied on the slide rule by the tabulated values of $\sin\theta$, and the mean spherical candle-power calculated in a few minutes. Naturally the mean upper and lower hemispherical candle-power can be obtained by a similar calculation.

There are also various shorter approximate methods of carry-

[1] This relation is worked out in many text-books. See, for example, *The Science of Illumination* (L. Bloch, translated by W. C. Clinton), p. 28.

ing out this operation, but they should be applied with caution, as they may not be strictly accurate when the polar curve is at all irregular.[1] Weinbeer has also devised an ingenious form of slide rule for carrying out this operation.[2]

There is also the well-known Rousseau method, which achieves the same result graphically, and until recently was almost invariably employed.

For an account of these various methods, readers may be referred to recent works by Bloch, Blok, and others (see Appendix).

The mean spherical candle-power is almost invariably worked out by one of the above methods, for the reason that whenever it is wanted the polar curve is usually also required. But apparatus has also been devised for determining mean spherical candle-power directly. Prof. Blondel was one of those who early devised an instrument of this kind, using elliptical mirrors to focus the light, which he terms a "lumen-meter."[3]

A simple method of determining mean spherical candle-power was proposed by Dr Alex. Russell in 1903.[4] This depends on the selection of rays at certain specified angles, so spaced that the integral effect of these rays gives a measure of the total flux. This is still regarded as one of the best methods of treating the problem. Wild has applied the principle to the testing of incandescent lamps, a series of mirrors being mounted at the intervals proposed by Dr Russell.[5]

The Matthews "integrating photometer" utilised a series of inclined mirrors distributed in a ring round the source to be tested, and each of them reflecting the ray of light on to a vertical matt white surface. By this means the necessary correction for sin θ is introduced, since the illumination due to each of the reflected rays is proportional to the cosine of the angle with the horizontal (complementary to θ). The total illumination of the white surface is thus a measure of the mean spherical candle-power. Each mirror is capable of adjustment so as to compensate for differences in reflecting power, or any

[1] See Bloch, *Illum. Eng.*, London, vol. ii., 1909, pp. 516, 682; also an article in the same Journal, vol. iii., 1910, pp. 31, 265. See also Bloch, *The Science of Illumination*, pp. 28–39.

[2] *Illum. Eng.*, London, vol. i., 1908, p. 559.

[3] *Éclairage Électrique*, 1895, pp. 385, 406, 538, 583; 1896, p. 49. *Bull. de la Soc. Int. des Électriciens*, vol. iv. (2nd Series), p. 39.

[4] *Proc. Inst. of Elec. Eng. London*, vol. xxxii. p. 631.

[5] *Illum. Eng.*, London, vol. ii., 1909, p. 197.

deviation from Lambert's law on the part of the white photometer screen. A more elaborate apparatus of the same kind has also been recently described by Krüss.[1] This makes use of a series of mirrors, like the Matthews photometer, but the reflected beams are collected by a series of lenses, each of which is stopped down to an appropriate amount to allow for the "$\sin\theta$" factor. The complexity of having so many mirror surfaces to keep clean perhaps explains why such types of apparatus, of which Prof. Blondel speaks with approval, have not come into very general use.

In order to be widely used it would seem that an appliance for measuring mean spherical candle-power should be easy to maintain and comparatively inexpensive to construct. These qualities are in the main possessed by the "globe photometer" devised by Prof. Ulbricht. This consists merely in a sphere of large dimensions (preferably as much as 2 to 3 metres in diameter), the interior of which is coated a dead white. The lamp to be tested is hung up inside the globe, and the rays are reflected to and fro in such a manner that the interior of the globe becomes uniformly illuminated all over and its brightness can be taken as a measure of the total flux of light. This brightness is measured by means of a suitable observation window, which is shielded from the direct rays of the illuminant tested by the insertion of a white screen within the globe. The globe is conveniently calibrated by inserting a source of known intensity.

The theory of the globe has been most exhaustively discussed.[2] Speaking generally, it is desirable to arrange that its dimensions are large in comparison with those of the lamp tested. The late Dr Corsepius has suggested several methods of utilising the globe for measuring mean hemispherical candle-power, but the accuracy obtainable in these circumstances would probably not be quite so great.

The globe photometer should presumably be well suited for measuring the absorption of globes and shades—which it is tedious and sometimes difficult to determine exactly by means of

[1] *Jour. f. Gasbeleuchtung*, 4th July 1908.

[2] Ulbricht, *Elektrot. Zeitschr.*, 1905, p. 512; 1906, pp. 50, 803; Bloch, *Elektrot. Zeitschr.*, 1905, pp. 1047, 1074; 1906, p. 63; Corsepius, *Elektrot. Zeitschr.*, 1906, pp. 669, 695, 803; Bloch, *Illum. Eng.*, London, vol. i., 1908, p. 274; Corsepius, *Illum. Eng.*, London, vol. i., 1908, pp. 801, 895; Sharp and Millar, *Trans. Am. Illum. Eng. Soc.*, vol. iii., 1908, p. 502.

FIG. 94.—General view of an Ulbricht globe photometer.

The inside is coated a dead white, and the source is usually lowered through an aperture at the top. The globe is made in two portions, which may be taken apart, allowing access to the interior of the globe.

polar curves. In the case of diffusing globes there appear to be no great difficulties, but it may be questioned whether any apparatus of this kind, however excellent, would give quite consistent results with highly focussing reflectors. In such cases the direction in which the reflector was tilted would surely have some influence.

Another matter which has been debated is the use of the globe for measuring the mean spherical candle-power of gas lamps. The enclosure of such lamps within a globe is apt to interfere with the supply of air and hence diminish the light.

It has always been assumed until recently that the spherical shape was essential to the accurate working of the globe photometer. Dr W. E. Sumpner,[1] however, has expressed the view that sufficiently accurate results might often be obtained by using a cubical box with whitened interior, and this is borne out to some extent by some experiments of Wild. Should this suggestion be confirmed it would mean a decided simplification, since a rectangular enclosure is much easier to prepare than a globe of the necessary dimensions. A cubical box of this kind, measuring 2 metres a side, has been installed at the National Physical Laboratory, and used for comparing lamps whose distribution curves do not greatly differ from each other.

Measurements of Illumination.

It is interesting to trace the development of photometry and to see how, as new illuminants made their appearance, more precise methods of measurement were introduced.

The development of gas lighting early in the last century did much to change this view, and we find that a considerable amount of pioneering work was concerned with the measurement of the illuminating power of gas. Subsequently, as new forms of burners and other illuminants made their appearance, the idea of measuring the illuminating power of the *source* became familiar. From specifying gas of a certain illuminating power people also came to speak of lamps as giving "so many candles" and this method is now applied generally to all illuminants.

But as early as 1883 Sir William Preece pointed out that although measurements of the illuminating power of sources of light are very desirable, they do not, strictly speaking, tell us

[1] *Illum. Eng.*, London, vol. iii., 1910, pp. 323, 392; see also Wild, *ibid.*, p. 549.

exactly what we desire to know. What we are really anxious to learn, he pointed out, is not only the light of the lamp given by the lamp used, but the actual intensity of illumination "on the surface of the book we are reading, or the paper on which we are writing, or on the walls on which we hang our pictures," etc. He therefore proceeded to describe an instrument for the measurement of illumination. This apparatus, which appears to have been among the first devised for this purpose, was subsequently improved by Sir William Preece in conjunction with Mr A. P. Trotter, and some of these early instruments are described in the latter's book on illumination. Among others who may be described as pioneers in illumination photometry may be mentioned the late Mr William Sugg.

The illumination at any spot is measurable in "foot-candles" or "lux," and can be stated quite irrespective of the way in which the lamps are arranged. For example, as explained on p. 141, an illumination of 3 foot-candles on the table would usually be considered sufficient for reading purposes, but this illumination might be produced in an infinity of ways—*e.g.* by a single local shaded light, by lamps distributed about the room, or by indirect light reflected from the ceiling. The essential point is that we have a certain value of illumination at the spot where it is required. In Great Britain and the United States illumination photometers are almost invariably calibrated in foot-candles, on the Continent the general practice is to measure in lux (metre-candles).

Since the date of Sir William Preece's first efforts a great many illumination photometers (or "illuminometers," as they are sometimes called), have been designed, and have proved of great assistance in illuminating engineering. Since most of the existing instruments have been repeatedly described in standard treatises, it hardly seems necessary to enter deeply into their constructional details, and we shall devote ourselves chiefly to the general principles underlying such apparatus. Readers may be referred to a useful paper on this subject read by Mr Preston S. Millar before the American Illuminating Engineering Society in 1907.[1]

Illumination photometers are intended mainly for testing lighting installations *in situ*. It is therefore desirable that they should be portable and simple to manipulate, and in order to secure these requirements some concessions may be made as

[1] *Trans. Am. Illum. Eng. Soc.*, vol. ii., 1907, p. 546.

regards accuracy. Some forms of apparatus, intended mainly for contract work where a high order of accuracy is essential, can hardly be described as illumination photometers, and are more in the nature of travelling photometer-rooms. Some of the movable photometers designed for testing lamps in the streets can be wheeled about readily enough, but are not, strictly speaking, portable and are not adapted for testing interior lighting. On the other hand, the greater space available naturally enables refinements of photometry to be introduced such as cannot always be provided in the more compact instruments.

During the last few years the tendency in the design of illumination photometers has been towards simplification. Attempts have been made to popularise such measurements, and to devise instruments which can be used by people of average skill and without much experience in photometry.

Some forms of apparatus have been designed based on acuteness of vision. For example, in the Simplex photometer, contrived by Dr Williams in the United States, the observer looked through an aperture at a card on which two sizes of type were printed. The card was placed at the spot where it was desired to measure the illumination, and the test was made as follows: The instrument was provided with a photographic wedge of graded opacity, and this wedge was slid along in front of the eye, thus progressively diminishing the apparent brightness of the card, until the larger type could just be read, while the smaller type could not. By means of the scale attached to the graduated wedge one could then infer the approximate illumination in foot-candles.

Other instruments of the "extinction" class likewise depend on the principle of progressively dimming the illumination until some small object just disappeared. An appliance of this kind is remarkably simple and compact, and at first sight possesses apparent advantages for approximate work. But experience shows that it is difficult to obtain even a very rough estimate of the illumination in this way. The result naturally depends on the acuteness of vision of the observer, so that the "personal error" may be considerable, and even the result attained by a single individual will depend to some extent on the condition of the eye at the time the test is made. In practice one finds that it is difficult to ascertain the exact point at which an object becomes indistinguishable. Moreover, as pointed out earlier in this chapter, methods involving vision at a low illumination

considerably below that to be tested seem to be open to general objection from the theoretical standpoint.

These considerations have led designers of illumination photometers to fall back on the ordinary methods of photometry and to compress into a small instrument what is practically equivalent to a photometric bench and comparison lamp. The design of the illumination photometer is mainly dependent on the choice of a suitable standard. Originally small lamps burning oil, benzene, etc., were employed. But flame sources are obviously inconvenient as portable standards. They are easily disturbed by draughts, must be maintained upright, and unless carefully supervised are not very trustworthy. It is now almost the universal practice to use a small electric glow-lamp fed by an accumulator. The invention of the metal-filament lamp has been a great boon in this respect.

The use of a small glow-lamp leads to considerable economy in space and enables the photometer to be tilted in any direction. The battery is in a sense a complication, but need not be incorporated in the instrument, and can be carried separately in the pocket or in a convenient form of case. Occasionally dry cells have been used, but a good accumulator of the unspillable type is decidedly superior, since the period of time over which it remains constant is much longer.

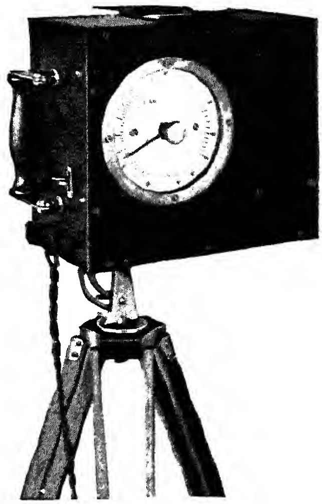
It will be observed that the illumination photometer is only to be regarded as the temporary custodian of the unit of light. It is calibrated in the laboratory before use, and will require to be checked from time to time as the lamp ages or the battery runs down. There has been some discussion as to whether a small ammeter and adjustable resistance should be included in the circuit, with a view to maintaining the current taken by the lamp constant and eliminating variation in the cell. Theoretically a control of this kind would seem advantageous, but it adds to the complexity, bulk, and expense of the apparatus. Moreover, seeing that the light varies as about the fifth power of the current, it is clear that a very accurate instrument, if any, should be used; an ammeter whose readings were at all untrustworthy would prove decidedly misleading.

In England most observers dispense with an instrument and prefer to rely on checking the instrument at frequent intervals. It is pointed out that in the course of a few hours' tests no perceptible change in pressure should occur, and this should be verified by testing the instrument before and afterwards. On

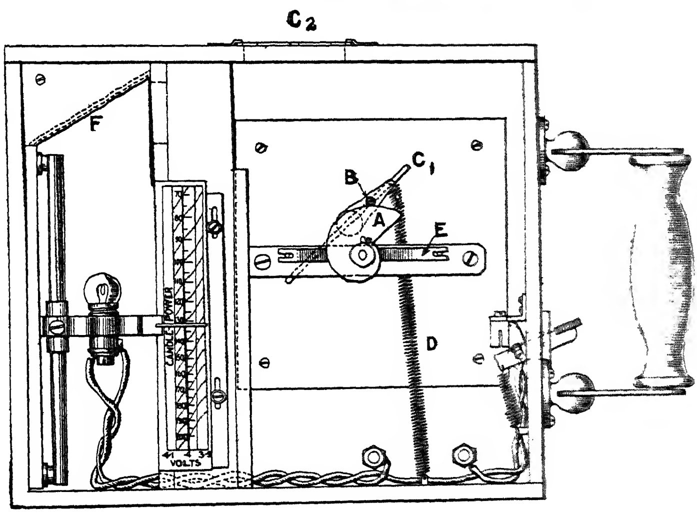
the other hand, there is more to be said for the use of an electrical control in the case of instruments intended for contract, as distinguished from experimental work; or for apparatus which may be used for weeks at a time by observers who have not access to a photometric laboratory.

The illumination photometer of to-day is of course not perfect, and we shall doubtless see marked improvements now that the practical utility of such instruments is well established. But during the last few years there has been a marked advance in simplicity and accuracy, and the measurement of illumination is already looked upon as quite a practical and convenient process.

A comparatively early type of English photometer was the instrument devised by Mr A. P. Trotter and developed by Messrs Everett, Edgcumbe & Co. The general nature of this photometer will be understood from fig. 95, *a* and *b*.



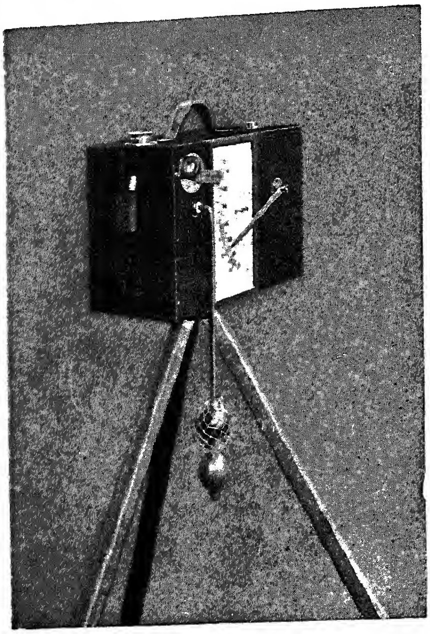
(*a*) General view.



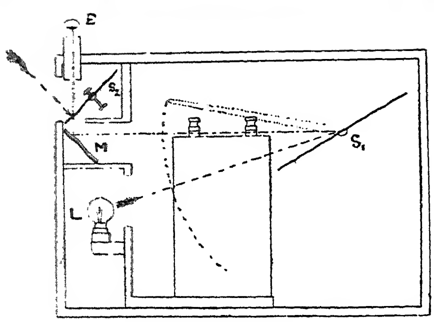
(*b*) Sectional view.

FIG. 95.—Showing Trotter illumination photometer.

The comparison source of light is in this case a small glow-lamp, the rays of light emitted by which strike the mirror, F, and are thus reflected on to the white diffusing screen, C_1. The observer looks at the white diffusing screen, C_2, which receives the illumination it is desired to measure. In this is cut a small aperture with very sharp edges. The observer is thus able to compare the illumination of the surface, C_1, with that of the screen, C_2. The latter can be rotated by means of the cam A so that the light strikes it at various inclinations, and the illumination is thus altered through a definite and convenient range from zero to 5 foot-candles. The actual value in foot-candles is obtained by observation of a pointer attached to the screen, C_1, moving on a scale on the outside of the box containing the photometer, as shown in the diagram.



(*a*) General view.



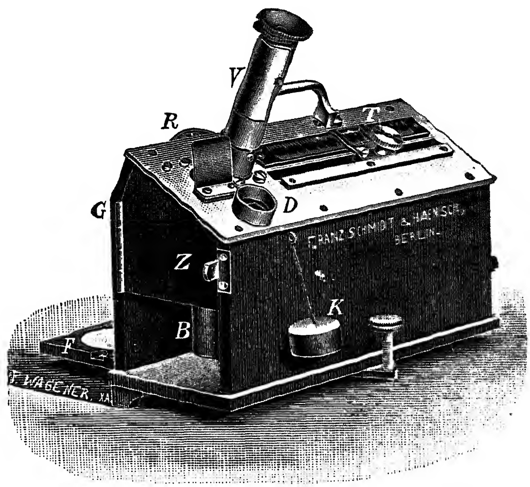
(*b*) Diagrammatic view.

FIG. 96.—Harrison illumination photometer.

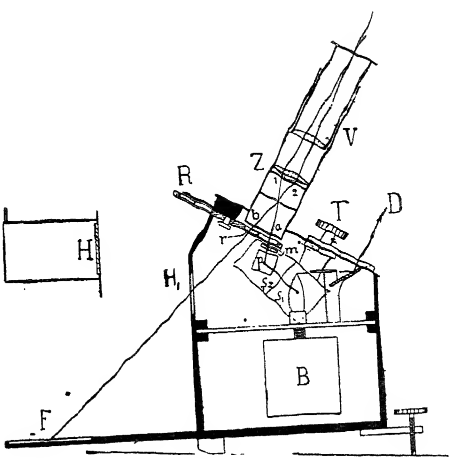
In the Harrison photometer (fig. 96) the standard of light consists of a small glow-lamp at L, which receives current from a small accumulator within the instrument, and which illuminates the movable screen, S_1. S_2 represents a white sector disc (*i.e.* a disc from which two symmetrical sectors are cut out) which is driven by means of a small air blast at any desired speed; on this screen is received the illumination which it is desired to measure.

The eye of the observer at E sees, in rapid succession, first, the illuminated white surface of the sector, S_2, and then in the mirror, M,

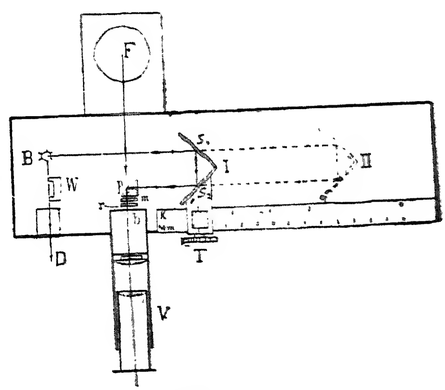
the illuminated surface of the screen, S_1. All that is necessary, therefore, is to alter the inclination of the screen, S_1, until no flicker can be perceived by the eye. The surfaces, S_1 and S_2, then appear equally bright. The



(*a*) General view



(*b*) Side view.



(*c*) Plan.

FIG. 97.—Illustrating Martens illumination photometer.

actual illumination at the screen, S_2, can be read off by means of a pointer attached to S_1, and moving on a scale graduated in foot-candles. In the position shown in the diagram the photometer is arranged to measure the intensity at an angle of 45° to the vertical, but, by tilting the photometer, the intensity at any measured angle may also be obtained.

In a recent modification of the instrument provision is made for the observer to use the instrument either on the flicker or equality of brightness plan, and also for the measurement of illumination in a horizontal plane to be accomplished.

As a type of German illumination photometer we may take the Martens instrument. In the illustration the standard is a small benzine lamp, but a metal-filament lamp fed from an accumulator may also be used.

The plaster of Paris surface, F, receives the general illumination, the intensity of which it is desired to measure. The rays from this surface pass into the telescope of the instrument at *b*; its brightness is compared with that of the frosted glass, *m*, illuminated by the small benzine lamp, B, the rays of which enter at *a*. The flame-height of this lamp is regulated to exactly 20 mm., this height being controlled by the observations through the window at D. The rays through the benzine lamp before proceeding to illuminate the plate, *m*, must suffer reflection from the pair of mirrors, S_1, S_2, as shown. By moving these mirrors to and fro by means of a rack and pinion arrangement, we can weaken or strengthen the brightness, of the illuminated plate, *m*, and can determine the relative values of the intensity of illumination, corresponding to equality of brightness in the field of view, by means of a scale calibrated direct in lux.

This alone would enable a range of illumination of 15 to 1 to be measured; in addition, a disc, *r*, is inserted in front of the plate, *m*, which contains a series of graduated smoked glasses, the densities of which are such that the illumination read upon the scale must be multiplied by 0·01, 0·1, 1·10, and 100 respectively.

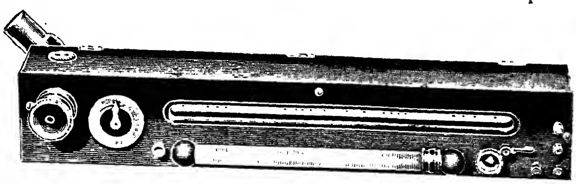
A considerable number of illumination photometers have been devised by Weber, Bechstein, Wingen, Krüss, Broca, and Blondel, and others. Generally speaking, the optical systems and details of these instruments are more elaborate than in the British patterns, and in the Brodhun street photometer some highly ingenious photometric refinements have been introduced.

On the other hand, some of the photometers devised by Ryan, Williams, and others in the United states were very simple and even primitive in construction, and this, while doubtless implying a certain sacrifice of accuracy, did much to popularise measurements of illumination. In later instruments refinements have been introduced. One of the best known American photometers is that due to Sharp and Millar.[1] This uses a tungsten lamp as standard, fed from a small accumulator. In the latest form the voltage can be checked and maintained constant by making the lamp one arm of a Wheatstone bridge, the balance being estab-

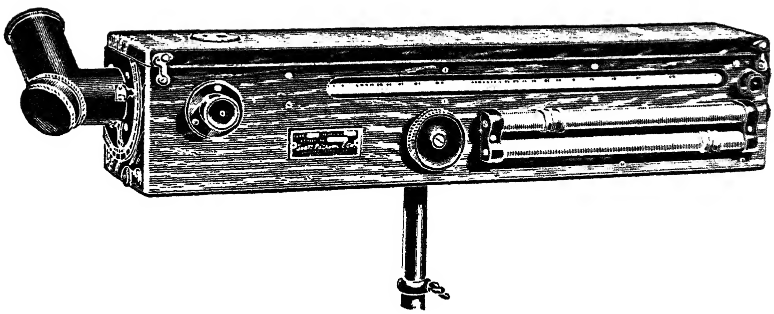
[1] *Illum. Eng.*, London, Jan. 1912; see also *Elec. World*, 25th Jan. 1908.

lished by means of an interrupter and telephone. By this arrangement, it is claimed, a minute deviation from the normal current can be readily detected.

The lamp within the instrument illuminates a translucent glass plate, viewed by means of a modified Lummer-Brodhun prismatic eye-piece. The illumination to be measured may fall upon a diffusing piece of translucent glass terminating an elbow tube, as shown in the illustration. This illuminated plate forms



(a) Small model.



(b) Standard model.

FIG. 98.—Sharp and Millar photometer.

the second portion of the photometric field, and is balanced against a screen illuminated by the small lamp within the instrument. It is also possible to remove this glass disc and to look through the tube at a detachable white screen, placed at any spot where it is desired to measure the illumination.

The balance is adjusted by moving the test lamp to and fro within the instrument by means of an external knob acting on a cord and pulleys. In order to increase the range of the instrument two screens, transmitting respectively 10 per cent. and 1 per cent. of the incident light, can be interposed in the path of the incident light. The photometer is also readily adapted for the measurement of candle-power.

It will be observed that the Sharp and Millar instrument,

like that devised by Weber and some other German authorities, can be readily used for the determination of surface brightness.

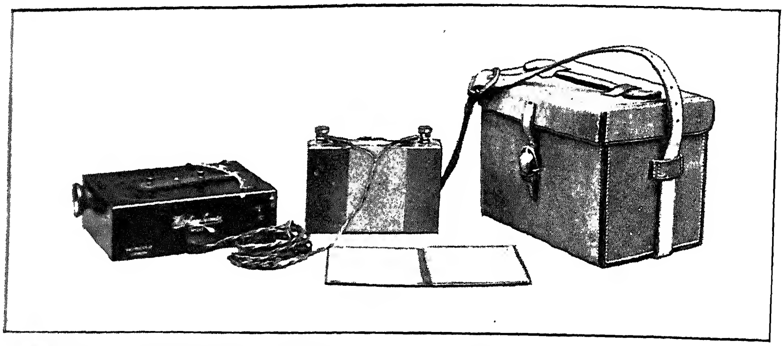


FIG. 99A.—General view of Holophane lumeter, with case, cell, and test-card.

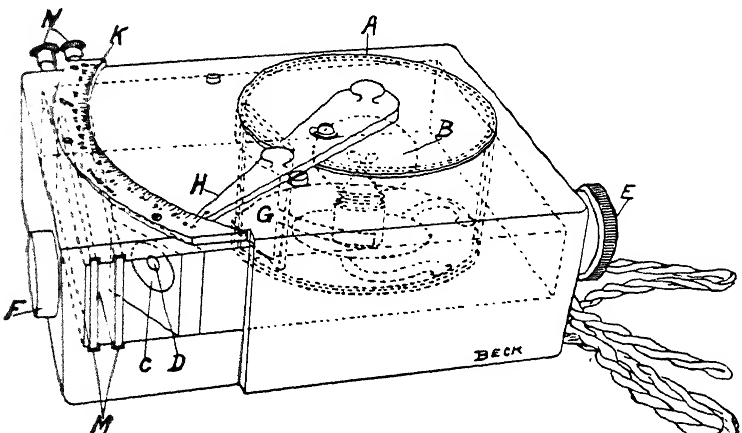


FIG. 99B.—Diagrammatic view of Holophane lumeter.

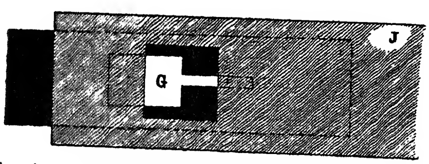


FIG. 99C.—Showing action of adjustable shutter in the Holophane lumeter.

By merely pointing the tube in the desired direction one can determine the brightness in foot-candles of a wall-paper, illuminated sign, or any distant object.

Quite a number of small and compact instruments, suitable

for the measurement of illumination, surface brightness, or reflecting power, have recently been introduced in England.

The Holophane lumeter apparatus, devised by one of the authors in conjunction with Mr V. H. Mackinney,[1] is shown in fig. 99A. The apparatus is only about 6 inches by $4\frac{1}{2}$ inches by $1\frac{3}{4}$ inches. It is packed away, together with the accumulator, in a small leather case, which can easily be slung over the shoulder.

The chamber containing the comparison lamp B is cylindrical, and is painted a dead white inside. G is a rectangular aperture covered by a ground opal glass plate, which is illuminated uniformly by the lamp inside, and in turn acts as a source of light and illuminates the photometric screen C. The lid A is attached to a cylinder fitting concentrically round the chamber, and having cut out of it an aperture of special shape (shown in fig. 99B). The pointer H travels on the scale as A is rotated.

With the aperture fully open, the pointer rests at the end of the scale and reads 1 foot-candle. But as the pointer is moved from this position, and the outer cylinder rotates, the exposed portion of the opal glass screen is uniformly reduced until, half-way along the scale, only the central slot is left, corresponding to one-tenth of the original area. The reading is therefore now 0·1 foot-candle. By moving the pointer further still this region is also uniformly reduced, and the reading diminishes uniformly from 0·1 to zero.

The observer points the instrument at the surface whose brightness he wishes to study, places his eye at E, at the same time pressing the contact at the base of the instrument and lighting the lamp. He then sees, through the central aperture D in the illuminated surface C, the surface to be tested, adjusts the pointer until photometric balance is secured, and observes the reading on the scale in foot-candles.

When it is desired to measure illumination, a white matt celluloid screen is used. This is placed at the spot where a test is to be made and its brightness observed as described above.

There are also (at M) two dark glasses, reducing the light respectively to one-tenth and one-hundredth, which can be placed in the path of the rays from the object studied by pulling out the knobs N. By introducing either or both of these glasses the scale of the reading can be multiplied by 10, 100, or 1000, so that it is possible to read up to 1000 foot-candles.

In calibrating the instrument the standard screen is placed at a convenient distance from a lamp of a certain candle-power, so that the illumination received by it is known. The position

[1] See "Surface Brightness and a New Instrument for its Measurement," by J. S. Dow and V. H. Mackinney (paper read before the Optical Society of London, 1910); also "New Apparatus for the Measurement of Light and Illumination," *Illum. Eng.*, London, Jan. 1912.

of the lamp within the chamber is then adjusted until the reading of the instrument, when towards the standard screen, is exactly correct.

The fact of using a detachable screen in this way has several advantages. It enables one to make measurements in any plane: moreover, only the screen, and not the photometer, is placed at the spot where a measurement is desired, and one can therefore often reach points that might otherwise be inaccessible.

There are also many cases (*e.g.* in studying the brightness of walls and ceilings in an interior) when measurements of surface brightness yield valuable information, and data of this kind have proved a very accurate means of determining the exposure in photography.[1]

FIG. 100.—The "Lightometer."

Surface-brightness instruments can be conveniently applied to determine the reflecting power of surfaces or to study the way in which the reflected light varies at different angles. As a practical instance of the value of such measurements, one may take the comparison of various materials for cinematograph screens (white canvas, aluminium powder, etc.). The instrument enables the apparent brightness of the screen, as it appears to the audience in front and to those at the sides of the theatre, to be determined very readily.

Another convenient and portable illumination photometer, designed by Mr Haydn T. Harrison, and recently brought out in England by the Benjamin Electric, Ltd., is the "Lightometer." This consists of a box containing a small glow-lamp at one end and a Bunsen screen at the other. Mounted on one side of the box is a sliding rheostat, enabling the light to be progressively varied, the corresponding variation being indicated on two scales reading respectively from 0·3 to 10 and from 0·001 to 0·3 foot-candles, according as four volts or two volts is applied to the standard lamp.

The Bunsen disc is pierced with a small central hole, and the observer, by means of a side eye-piece in the box, can look

[1] Dow and Mackinney, paper read before the Royal Photog. Society, London, 28th March 1911.

through the aperture in the photometric screen and so determine the surface brightness of distant objects.

Yet another small instrument of the surface-brightness type, the "Luxometer," has recently been introduced by Messrs Everett, Edgcumbe & Co. This is essentially a modification of the Trotter photometer.

It will be seen, therefore, that during the last few years quite a number of new illumination photometers of a very compact and portable type have been brought out in England. The tendency in their design has been towards simplicity and ease of manipulation, and the measurement of illumination has become quite a practical and familiar process. In recent papers read before the Illuminating Engineering Society the results of a considerable number of measurements in schools and libraries, works, etc., were given, and there is no doubt that these data will go far towards establishing standards of the illumination desirable for different classes of work.

The Factory Department of the Home Office in this country have also recognised the extreme value of illumination measurements in providing a record of industrial lighting conditions, and in a recent report by Mr D. R. Wilson the results of no less than 2500 measurements in 125 different cotton and textile works were presented. Corresponding data for iron foundries have since been published.[1]

There has been much discussion as to the best system of specifying the illumination for indoor lighting. As a rule the place where the measurement should be made is obvious. For example, in school or library lighting the essential thing is to ensure that the illumination is sufficient on the desk, table, or rack where the reading or writing is carried on; and the same applies in the case of many factories, where the workers are seated round tables. In some trades (*e.g.* watchmaking, engraving, etc,) a very high local illumination at some particular spot is needed, and measurements would naturally be made at the particular point where this light is required.

In general one may assume that the illumination in a room is mainly needed at about the ordinary table level, and this is termed the "working plane." This is the chief justification of the method generally adopted on the Continent, and to a large extent in this country, of making measurements in a horizontal plane 1 metre high. But it may sometimes be necessary to

[1] See Report of H.M. Chief Inspector of Factories for 1911 and 1912.

supplement such measurements by tests in a vertical plane; for example, in a school-room one would naturally ascertain the illumination on the blackboard surface, as well as the pupil's desks. Again, it is often desirable to determine not only the general illumination in an interior, and the local illumination at special points where work is done, but also the surface brightness of surroundings, in order to describe an installation completely. Another point that should receive attention is the "diversity coefficient," *i.e.* the degree of variation of illumination in various parts of a room.

Standard methods of measuring illumination have been proposed by the Verband deutscher Elektrotechniker.[1]

This body has advocated that comparisons of installations (both indoor and outdoor) should be made on the basis of mean horizontal illumination measured at a height of 1 metre above the floor or ground, and that in addition the mean and maximum values should be stated, the diversity coefficient being expressed in terms of the ratio of the maximum to the minimum. The "specific consumption" of an installation is defined as the consumption of gas or electricity per lux per square metre of floor illumination. Similar methods are used by some firms in this country. International agreement on a common method of testing seems desirable, and will doubtless be arrived at before long.

It is now very generally agreed that indoor installations are best compared in terms of horizontal illumination. By measuring the illumination in a horizontal plane we automatically add up the constitutions of the various lamps in a room, and we also come closest to a true estimate of their combined illuminating effects. The method, of which Mr A. P. Trotter has long been a consistent advocate, seems to be the best compromise in the circumstances. Illumination photometers should have no projecting parts above the level of the test-plate, such as might obstruct light coming from certain directions, and it is also necessary to avoid shadows being cast by the person of the observer. As a rule no difficulty is experienced in avoiding this source of error, but in the case of installations using a large number of separate points of light some care is necessary. It has been claimed as an advantage for the detachable test-plate (such as is used, for example, with the Holophane lumeter) that

[1] *Elektrot. Zeitschr.*, 15th April 1910; *Illum. Eng.*, London, vol. iii., 1910, p. 403.

the observer, looking at this screen from a distance, is less likely to cause such shadows.

Another point that deserves notice is the nature of the horizontal screen on which the illumination is received. In order that it may satisfactorily add up the illumination due to all the rays striking it at varying obliquities, the screen should obey Lambert's law as exactly as possible. Some authorities have advocated special screens made of compressed plaster of Paris and magnesia, but it appears that a good dead-white surface can be more easily obtained by using white celluloid ground with moist pumice powder, while even a piece of dead-white cardboard may be said to give sufficiently accurate results for commercial purposes. The observer should select his position so as to avoid, as far as possible, the consequences of any direct reflection that may exist.

The general order of accuracy attainable with the present types of illumination photometers deserves to be studied more closely. It seems probable that with the best instruments results within 10 to 15 per cent. should be obtained, and this is ample for most commercial work. Experienced and skilful observers claim to work to a considerably greater accuracy by taking special precautions.

For experimental purposes illumination measurements can also be conveniently applied for outdoor work, *e.g.* in testing the uniformity of illumination in streets, yards, and railway platforms, etc. But here, again, the distinction to be drawn between measurements which are merely experimental, and for the sake of gaining information, and tests which are undertaken to ensure compliance with a contract, or as a basis for competitive tenders, should be carefully borne in mind. The necessity for such a distinction was illustrated by the prolonged discussion on Mr Trotter's paper on the "Standard Specification on Street Lighting."[1] In the draft report presented by the joint committee appointed to consider this question it was suggested that measurements of street lighting should be based on the determination of minimum illumination at a height of 39 ins. (1 metre) from the ground. Some speakers were warmly in favour of this method, agreeing that only in this way could a true idea of the combined illuminating power of several lamps be obtained, and

[1] *Illum. Eng.*, London, May and June 1913. See also articles in this Journal for May and July 1911, and a valuable report presented to the Nat. Elec. Light Association in 1913 (*Illum. Eng.*, London, Sept. 1913).

pointing out that illumination measurements could be more expeditiously carried out than tests of candle-power. On the other hand, the advocates of candle-power urged that the system of illumination measurement, however useful for indoor lighting, was not sufficiently accurate for street work; and that special difficulties would be caused by the fact of the illumination to be measured being in general so low and the rays striking the photometer screen so obliquely; also that uncertainties might arise through the reflection from the sky and from the neighbouring buildings, etc. Objection was also taken to the measurement of minimum illumination; on the other hand, to ascertain the average illumination in a large street or square would clearly entail a considerable amount of work.

The matter is still under discussion. For the moment, all that can be said is that the measurement of illumination in the streets is admittedly a more difficult matter than in the case of indoor lighting, where the specification and measurement of candle-power is already becoming obsolete. In streets and open spaces the comparative advantages of measuring candle-power and illumination are still debatable.

Daylight Photometry.

It may be well to conclude this chapter by a few words on daylight photometry.

Measurements of daylight differ from those undertaken by artificial light mainly in two respects—the much higher values of illumination to be tested, and their extreme variability. Daylight, besides altering with the time of day and the season of the year, is very much affected by climatic conditions; few people realise the enormous difference between the light on a bright, sunny day and on a dull, cloudy one.

The illumination outdoors on a bright, sunny day will often amount to several thousand foot-candles, and even in a room values of several hundred foot-candles are frequently met with near the windows. Illumination photometers intended for this class of work should therefore be adapted to measure at least 1000 foot-candles.

It sometimes happens that one desires to measure the absolute daylight illumination in a room. But usually we are more concerned in comparing the illumination in different parts of a room or in relating it to the illumination out-of-doors. Daylight

measurements are chiefly relative. It is therefore convenient to interpose a tinted gelatine screen in the path of the rays of light entering the photometer, making the colour exactly the same as that of the tungsten lamp; without the help of such a screen many people find a difficulty in daylight tests, and for purely relative measurements the amount of light absorbed by it is immaterial.

A great deal of work has been carried out on daylight measurement, partly in connection with meteorology and photography, but chiefly by engineers and others interested in the planning of schools. As an illustration we may mention the researches of Basquin [1] and Nichols [2] in the United States and of L. Weber [3] in Germany. The latter was among the first to devise methods of testing daylight illumination in schools, but there is now quite a literature on the subject.

The study of daylight illumination is one of considerable consequence to the architect. In planning important new buildings it would often be very useful to be able to predetermine exactly the effect of windows of a certain size and position. Theoretically, assuming the average daily brightness of the sky (estimated by Basquin at about 2·5 c.p. per square inch), it should be possible to calculate with fair exactitude the illumination derived from a window of specified area, and by the aid of published data to infer how this illumination would vary at different times in the year. But such calculations assume a sky of uniform brightness such as would exist in an average day. It is obviously difficult to estimate the effect of direct sunlight from a sky that is constantly changing. In England (unfortunately) a cloudy sky is very general, only a comparatively small percentage of the annual daylight consisting in direct sunlight.

It has been suggested that valuable information might be obtained previous to the erection of a building by constructing small models, which could be illuminated by some convenient form of artificial sky, or even by normal daylight. Tests with a surface-brightness photometer could then be made in the interior of the model, with a view to ascertaining the intensity and uniformity of illumination likely to be secured with the

[1] *Illum. Eng.*, New York, vol. i., 1901, pp. 724, 823, 930, 1016.

[2] *Trans. Am. Illum. Eng. Soc.*, May 1908.

[3] *Tagesbeleuchtung der Städtische Schulen in Kiel* (Lipsius u. Tischer, 1908); see also *Illum. Eng.*, London, vol. iv. pp. 243, 669.

proposed window space. The effect of any alterations could be conveniently determined.

The problem of providing adequate natural light in a building may be studied in two distinct ways. Architects seem to have hitherto relied mainly on empirical rules specifying the window area necessary for a room of certain dimensions. A general rule that occurs in much legislation relating to school-rooms is that the window area should not be less than one-fifth of the floor area of the room. Cohn in Germany adopted the method of specifying that the solid angle subtended by the window at any point in the room should not be less than 50 "square degrees." Weber has gone a step further by proposing a minimum lighting efficiency (*i.e.* percentage of area unobstructed by trees, surrounding buildings, etc.) for the windows.

But it is clearly difficult to devise any empirical rule that will always meet local conditions, and photometric experts have therefore sought to devise some general principle, connecting the interior illumination with the unobstructed brightness outdoors, which would settle once and for all whether the excess of daylight was adequate.

This method is still in the experimental stage, but several devices have been proposed. For example, the simple little Thorner illumination tester is based on the comparison of the brightness of an image of the sky with the illumination at any point in the room studied. The details are shown in fig. 101.

The mirror *e* reflects light from the sky on to the lens *d* which forms an image at the point *a*, where there is a small aperture. At *c* is a piece of white card. The observer, looking along the line *b a c*, thus sees through the aperture at *a* a spot which appears dark or light according as the illumination at *c* is less or greater than the brightness of the sky image. The lens is stopped down to a value so calculated that in a well-lighted room the spot should never appear dark.

The instrument is carried backwards and forwards, in order to ascertain whether this condition is complied with in all parts of the room. The simplicity of the method is attractive, but there are many offices in London streets from which the sky is only visible from a small part of the room (or possibly not at all), and where the instrument could hardly be applied. Weber, in his "relative photometer" has adopted a more elaborate method of employing the same idea. Ruzicka[1] has used the same method in connection with small models of school-rooms,

[1] *Illum. Eng.*, London, vol. i., 1908, p. 539.

and has suggested as a principle that the illumination in the darkest part of the room should not be less than one-hundredth of the sky brightness.

There is another method, originally devised by Mr A. P. Trotter and recently developed by Mr P. J. Waldram,[1] of attacking the problem. This is also based on the idea of specifying that the darkest part of any adequately lighted room should receive a certain fraction of the total unrestricted daylight out-

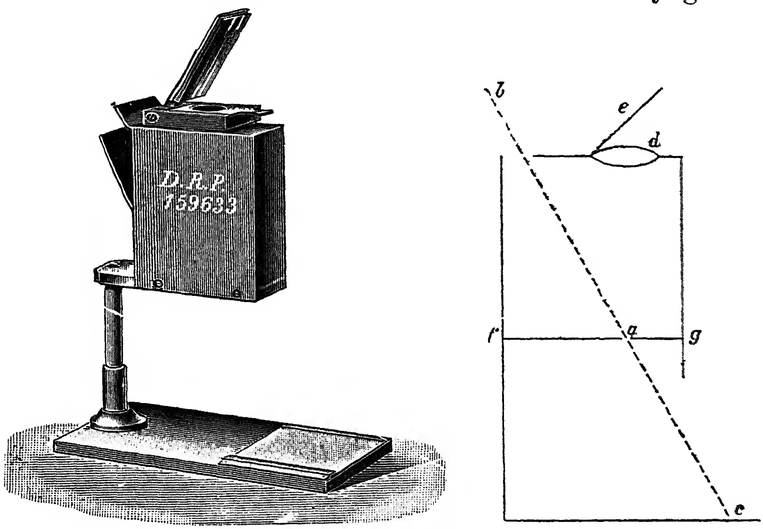


FIG. 101.—The Thorner illumination tester.

side. This fraction should depend only on the nature of the building, and should be independent of daylight variations with season and time of day. Like the Thorner apparatus, it demands a uniform white sky.

With a suitable instrument one could obtain this ratio by merely measuring in succession the illumination in the room and the unrestricted illumination outdoors. But the latter value is often too high to be conveniently measured, and it may also be difficult to find a place where the full effect of daylight, unobstructed by trees or buildings, can be obtained.

The method employed by Mr Trotter and Waldram consists in fitting to the photometer a tube with a terminal aperture, the size of which is so calculated that light from only a measured fraction of the entire sky (say, one-thousandth) is admitted.

[1] *Illum. Eng.*, London, vol. i., 1908, p. 811.

The reading of the instrument is then empirically assumed to give one-thousandth of the total unrestricted daylight illumination. (Strictly speaking, the percentage will be less than this, since allowance must be made for the varying obliquity at which rays from the sky strike the photometer surface. But the difference is a constant one, and would therefore not affect comparisons of different buildings.)

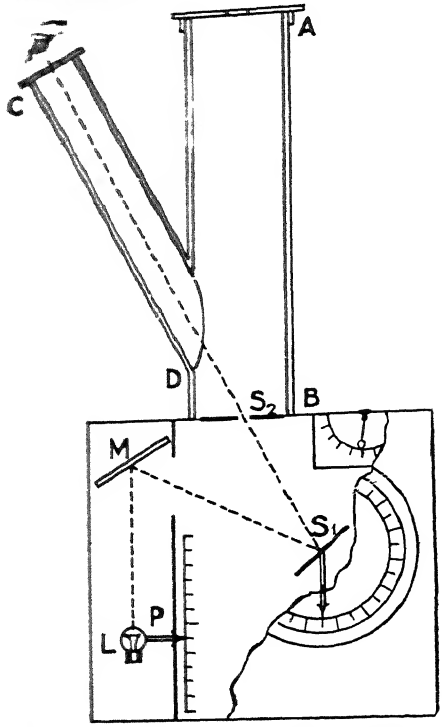


FIG. 102.—Device for measuring daylight, originally proposed by Mr A. P. Trotter and recently employed by Mr P. J. Waldram.

A tube, AB, with blackened interior is placed above the photometer screen, S_2, and the aperture at A allows a calculated fraction of the illumination from the total sky area to be received. The eye of the observer looking down the side tube, CD, is able to compare the brightness of S_2, S_1 and to make a measurement with the Trotter photometer in the ordinary way.

In this system a white sky of uniform brightness is assumed. Even on a cloudy day some difference in the result may be expected, according to the direction in which the tube is pointed, and it seems, therefore, desirable to adopt the precaution of always pointing the instrument to the zenith.

Mr Waldram has determined the ratio between the interior and outdoor illumination for a number of different buildings in London, and suggests that an office enjoying a proportion of 0·001 of the outside illumination in the centre of the room might be considered reasonably well lit.

In the House of Lords and the House of Commons considerably lower values are recorded.

Since the above was written, Mr Waldram has read a paper before the Illuminating Engineering Society of London, making a number of novel proposals and carrying these researches a step further.[1] Prof. L. Weber has suggested that the worst-lighted

[1] *Illum. Eng.*, London, vol. vii., Jan. 1914. This number contains also a summary of foreign researches by Dr J. Kerr and Dr E. H. Nash, and

desk of a school-room should receive 0·5 per cent. of the unrestricted daylight illumination out-of-doors—a result in substantial agreement with that reached independently by Mr Waldram. It may be observed that, with a uniformly bright sky, the unrestricted daylight illumination is equal to the surface brightness of the sky, measured in foot-candles. The opinion is now gaining ground that the daylight ratio for a building is most accurately obtained by direct measurement of the illumination from the complete sky-hemisphere, or from a quadrant of the sky, as is visible from the window-sill; in this case the error due to a sky not being uniformly bright is usually less than when the brightness of only a small portion is studied.

The application of photometry to daylight problems is still developing, but it has already been proved to have great possibilities. A special instance of the utility of photometric tests is in connection with ancient light cases, where the effect on the light of a neighbouring erection is often a matter of conjecture and the task of the judge by no means an easy one. It would seem that important confirmatory evidence could often be obtained from photometric tests, and their value has already been substantiated in a number of cases.

In the course of this chapter we have referred somewhat fully to the problems of photometry, in order to show the thorough manner in which the subject is being taken up, and the wide field for research which photometry offers to the physicist and physiologist.

But although there are many scientific problems still to be solved, the practical value of photometry both in the laboratory and for measurement outside in the school, office, or factory, etc., is now fully established. The demand for accurate tests of the candle-power of lamps, the distribution of light from shades and reflectors, etc., has grown very rapidly, and manufacturers are no longer satisfied with the rough and ready methods of the past. The measurement of illumination has also made great strides, and we may expect that before long it will be tested with the same accuracy and certainty as temperature, or any other of the factors essential to daily life.

contributions bearing on daylight illumination from a number of foreign correspondents. See also an Interim Report on the Daylight Illumination of Schools (*Illum. Eng.*, London, vol. vii., July 1914, p. 359).

CHAPTER VIII.

GLOBES, SHADES, AND REFLECTORS, AND CALCULATIONS OF ILLUMINATION.

The Chief Functions of Globes, Shades, and Reflectors—Diminution of Intrinsic Brilliancy, Direction of Light, and Softening of Shadows—Some Common Types of Shades and their Defects—Globes for Indoor and Outdoor Lighting—Various Diffusing Surfaces—Use of Obscured and Prismatic Glass Globes—Amount of Light absorbed by various types—Various Materials used in Design of Shades and Reflectors (Cardboard, Metal, Prismatic, and White Glass, etc.)—Combined effect of Direct and Diffused Reflection—Principles used in Holophane Reflectors—Illuminating Engineering Calculations—Spacing Rules for various Illuminants—E, I, and F type Reflectors and use to produce Uniform Illumination—Calculations based on Flux of Light—Globes and Reflectors for Street Lighting—Dioptric Globes and Improved Distribution of Illumination—Special Forms of Reflectors—Indirect and Semi-indirect Lighting—Illumination from the Cornice and from Suspended Bowls, and Shadow Effects produced—Design of the Fitting to harmonise with Architectural Features—Pedestal Units—Miscellaneous Lighting Appliances for illuminating Desks, Hoardings, Pictures, etc.—The Artistic and Decorative Considerations of Fixture Design.

In the last chapter, when dealing with the determination of polar curves of light distribution from illuminants, it was pointed out that such curves can be very materially modified by the use of suitable globes, shades, or reflectors. Such appliances play an important part in illuminating engineering. There are few sources of light which can be considered complete unless they are adequately shaded; and the recent introduction of so many new illuminants, many of them giving their maximum light in quite different directions, has given the subject an importance which it did not possess in the past.

The Chief Functions of Globes, Shades, and Reflectors.

The general principles governing the design of shades and reflectors were summarised in a recent paper before the Illuminating Engineering Society in London, by J. G.

Clark and V. H. Mackinney.[1] Their chief functions were stated to be:—

(*a*) To tone down the excessive brilliancy of an illuminant.
(*b*) To direct the light where it is chiefly needed.
(*c*) To soften the shadows.
(*d*) To serve as a decorative object.

Naturally these four functions are not always equally important. We meet cases, for example, where the economical direction of light is the most vital matter, and interest centres mainly on the polar curve. There are other branches of work where artistic considerations are of paramount importance, and we find that the decorative appearance of a shade and the nature of the shadows cast by it are the chief points to be considered.

But in the great majority of cases—one might almost say in *every* case—the first point (namely, the toning down of excessive brilliancy) has to be borne in mind. Even in the days of candles and oil lamps the art of shading was by no means neglected, but the advent of the modern, powerful, and intensely brilliant lamps has made it of greater importance than ever before.

As far as concerns intrinsic brilliancy, the art of shading is a comparatively simple matter. Mr John Darch[2] has laid stress on this point, and has shown how the shades in the average room should be arranged so as to screen the direct rays in all directions likely to be prejudicial to the eyes, and yet not to absorb more light than is strictly necessary. The principles suggested will be understood from fig. 103, and may be said to apply generally to domestic lighting.

Some judgment is necessary in selecting the materials for the shades. If these absorb too much light, a patchy effect on the ceiling is apt to be produced.

It has been suggested that the intrinsic brilliancy of shades should preferably not exceed about 2 to 5 c.p. per square inch (which is not far removed from the brightness of an average white sky), and there are some who would fix the limit as low as one-tenth of a c.p. per square inch. Insistence on the lower limit would perhaps be too severe; but it seems feasible (at least in the case of indoor lighting) to secure that

[1] *Illum. Eng.*, London, vol. vi., March 1913.
[2] "The Art of Shading," *Illum. Eng.*, London, vol. ii., 1909, pp. 83, 173.

the eyes should not, under ordinary circumstances, encounter surfaces whose brightness exceeds 5 c.p. per square inch (approximately equivalent to a surface brightness of 2250 foot-candles).

The majority of silk shades have little directive power. They "soften" the light, but are not usually of much value when we desire to concentrate it for some special purpose. It has been pointed out that for industrial work, and even in the home it is almost always possible to name some spot where the illumination is mainly required.

In all such cases we are justified in selecting a shade or

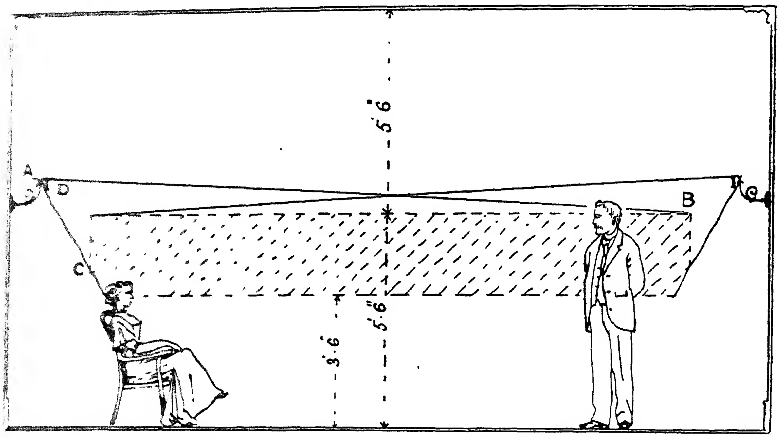


FIG. 103.—Arrangement of shades to screen lights from the eyes of people in a room, with minimum obstruction of light.

Light is screened over the "danger area" (shown by transverse lines), where direct rays would otherwise be apt to meet the eye (J. Darch).

reflector so shaped as to concentrate the light mainly over the region where it is obviously needed. At the same time we must allot sufficient light to the upper part of the room to enable the surroundings to be clearly visible, but the amount of illumination required for this purpose is usually comparatively small. The choice of the shading appliances has a vital influence on the economy of the installation. By merely substituting efficient types of reflectors it is sometimes possible to use lamps of much smaller candle-power than those previously employed, and thus to make a saving almost as great as might be derived from the introduction of metal-filament electric lamps in place of carbon-filament ones. Moreover, an unshaded lamp may be not only useless but actually prejudicial. For example, a brilliant un-

screened source placed at the head of a flight of stairs might easily dazzle the eyes of a person and lead him to stumble; whereas if such a source were screened with a suitable reflector, the light would be directed downwards on the stairs, where it is really needed, and would not escape in directions where it merely causes inconvenience. "Light on the object, not in the eye" is a motto that has often been quoted in this connection.

The third function of a shade, the softening of shadows, deserves some study in connection with interiors of architectural or artistic value. An unscreened source of great brilliancy, besides giving an impression of glare, tends to give undesirably sharp, dense shadows. From the artistic standpoint such "hard" shadows are usually disliked. Shadows there must be in order to show up the features of mouldings, columns, alcoves, etc., but in general the architect prefers that the shadows should be soft, that their edges should be somewhat indistinct, and that violent contrasts in light and shade should be avoided. For industrial purposes very sharp shadows, such as are cast by a naked arc light, are also objectionable. They are apt to produce a confusing effect, leading people to suspect a hole in the floor where none exists, or *vice versa*; accidents at the docks, in foundries, etc., have sometimes been ascribed to this cause. Moreover, when sharp, dense shadows are caused by projecting objects, there will usually be corners or recesses where there is insufficient light. In practice it is often desirable for light to penetrate completely into every corner of a room.

The softness or hardness of shadows is chiefly a matter of the size of the luminous source. By extending the dimensions of a globe or reflector we practically increase the area of the light-giving surface, which has the desired softening effect.

Another function of a shade, the removal of "striations," may well be mentioned here. It not infrequently happens that a small source, enclosed in a clear glass globe or chimney, gives a decidedly "streaky" illumination. These striations are apt to be very trying to the eyes, especially if, owing to vibration, there is a constant flicker. By inserting a diffusing glass surface in the path of the rays, or even by placing an extensive white surface behind the illuminant, the objectionable streakiness can be made to disappear.

The consideration of the decorative qualities of shades and globes is best left to a later stage in this and the following chapter.

SOME COMMON TYPES OF SHADES AND THEIR DEFECTS.

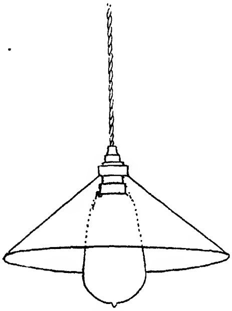
We will now proceed to the discussion of some typical shades and reflectors, pointing out their merits and drawbacks and the chief points of interest in their design. In fig. 104 are shown some common methods of shading, most of which only comply imperfectly with the requirements stated above.

The shallow opal and enamelled reflectors frequently employed with electric lamps at the present day are open to several objections. Even for the carbon-filament lamp they were not entirely satisfactory. They did not completely screen the carbon filament from the eye. The metal-filament lamps, having longer bulbs, project still further, so that the bright filament is usually visible to the majority of people present in a room. Moreover, they only enclose a small portion of the total flux of light emitted from the source, so that their "directive power" is small. It has been pointed out that in the case of the metal-filament lamp only a very small proportion of the light is directed downwards. The maximum intensity is horizontal, and most of the light escapes out sideways in such a way as to dazzle the eyes of people in the neighbourhood. The directive influence of a good reflector is therefore specially valuable.

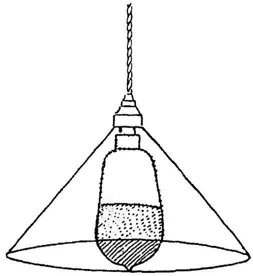
It is hardly necessary to point out that in order to be of service in directing the rays of light, a reflector must enclose the source sufficiently to receive these rays on its reflecting surface. Such a reflector as that shown in fig. 104, *e*, for example, can only slightly influence the distribution of light from an upright incandescent mantle.

The great majority of the rays never reach it, but merely stream out horizontally and cause glare. The amount of light absorbed by such a reflector is naturally small—but merely because so little light impinges upon it. This type of reflector shows, in an aggravated form, the defects characteristic of the shallow reflectors referred to above. In practice we almost always require the great majority of the light to be directed *downwards*, and the forms of reflectors shown in figs. 104, *b* and 104, *h* are much more satisfactory in this respect.

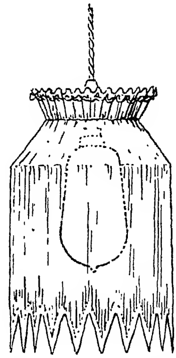
On the other hand, it is not desirable to go to the other extreme and to surround a source completely by light-obscuring material in the manner shown in fig. 104, *c*. One occasionally sees lamps completely shrouded with coloured silk or paper. Naturally, these materials soften the light, but very little of it



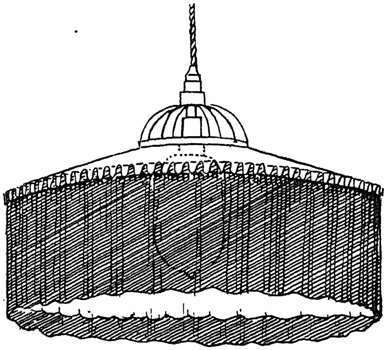
(*a*) Shallow opal shade, incompletely covering filament and permitting glare.



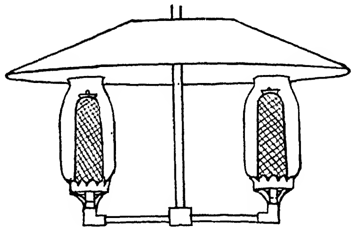
(*b*) A more satisfactory shade. Filament properly screened by opal shade and frosting of lamp.



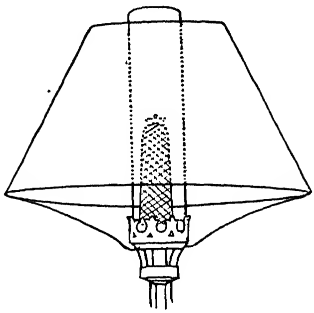
(*c*) This silk shade screens the lamp completely, but will absorb a great deal of light.



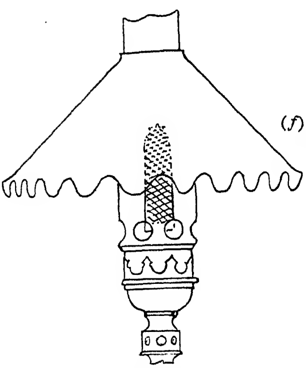
(*d*) A better arrangement. The opal reflector and inner white silk surface reflect much of the light downward.



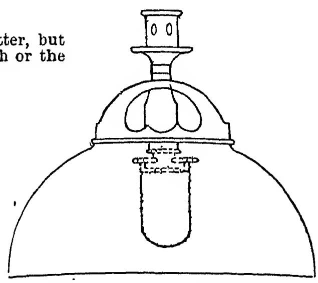
(*e*) This reflector is of very little use. The mantles are unscreened, and very few of the rays reach the reflector at all.



(*f*) This opal shade is much better, but should not be placed too high or the mantle becomes visible.



(*g*) This type of shade leaves a great part of the mantle unscreened.



(*h*) A good shade for concentrating the light. The mantle is completely covered.

FIG. 104.—Typical shades, and defects to be avoided.

escapes through their folds. A much better form of shade is that shown in fig. 104, *d*. It utilises a white opal plate above the lamp, and there is an inner lining of white silk which reflects most of the light downwards. Yet it allows enough to penetrate through the outer tinted silk and to give the pleasant effect which makes the silk shade such a favourite for domestic lighting.

Another excellent method is to suspend the silk covering over some suitable forms of prismatic glass reflector.

Tinted semi obscured glass shades of the type sketched in fig. 105 have also defects. As a rule they encompass the source closely and screen the source from the eyes. But they absorb much of

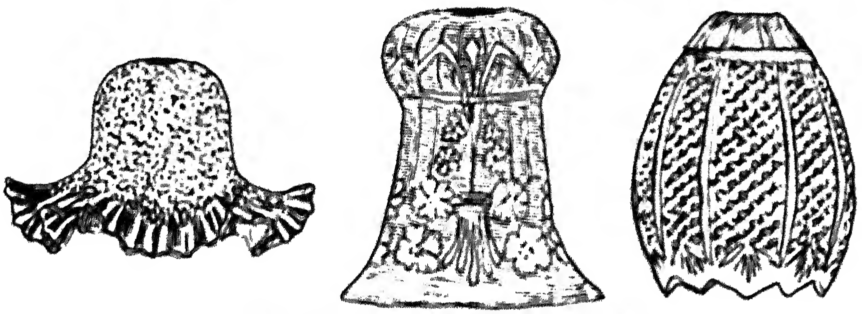


Fig. 105. Typical tinted and cut glass shades.

the light emitted horizontally (which is usually the maximum direction) instead of reflecting it, and their efficiency is therefore usually poor. Moreover, the appearance of such shades is generally inartistic. The shape of the filament or mantle may often be seen through the glass, which is not evenly illuminated, and the patterns traced on it often give rise to objectionable bright points of light; this last defect is characteristic of inferior cut glass.

Fringes of beads have a certain decorative value, but do not always diffuse the light from the source behind them and are apt to be glaring. In addition, they have, of course, little directive effect.

Globes for Indoor and Outdoor Lighting.

In the scientific design of globes and reflectors the direction of the light plays an important rôle. It is necessary, in the first place, to select materials which are sufficiently durable or ornamental and which have the requisite reflecting power, and

in the second place, to shape the surfaces in such a way as to give the desired polar curve of light distribution, and at the same time screen the illuminant sufficiently to avoid glare.

A word or two may first be said on the subject of globes. By this term is understood an appliance (generally made of glass) which more or less completely encloses the source. With the materials employed for most globes in use at the present time it is hardly possible to alter the polar curve of light distribution very radically. When a source of light is enclosed in a globe made of frosted or milky glass the globe tends to become itself a source. The small diffusing particles on the glass scatter the light in the manner shown in fig. 106. There is usually present a small amount of transmitted light, and in this case we can often see a blurred image of the source itself through the luminous surface of the globe.

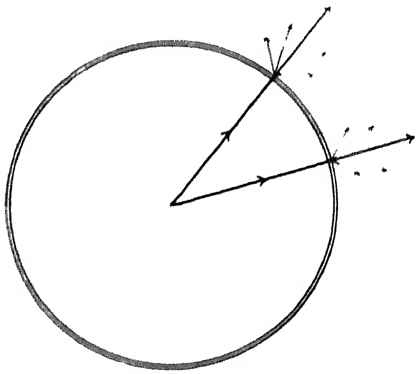
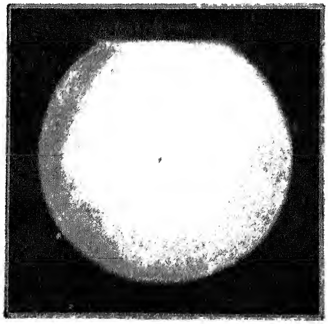


FIG. 106.—Mixture of diffused and directly transmitted light from glass globe with roughened surface.

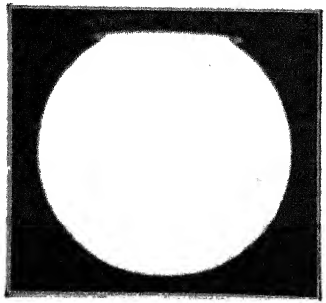
The perfection with which the light is diffused (*i.e.* the degree of uniformity of brightness on the globe surface) depends largely on the density of the obscuration. Some very dense forms of opal glass appear uniformly bright all over, and scatter the light very well, but in so doing absorb a great deal of light. On the other hand, good diffusing power and high absorption do not necessarily go together. There are some varieties of glass which show an image of the source (usually reddish in appearance) and yet absorb a great deal of light, and there are others which appear uniformly bright all over and conceal the source most effectually, and nevertheless have a comparatively low absorbing power. There seems a need for some standard method of defining the diffusion of light by globes. E. L. Elliott, in a paper presented at the Convention of the American Illuminating Engineering Society in 1912, suggested that the term "diffusing power" should be used to denote the ratio between the brightest and darkest portions of a translucent globe or shade. A globe which appears uniformly bright all over would be said to have a diffusing power of 100. It may, however, be urged that

absolutely uniform brightness is not desirable on artistic grounds, although an irregular "spotty" effect should certainly be avoided.

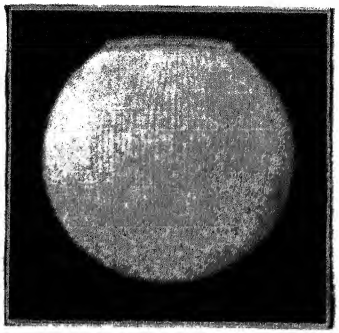
The result of this action of an obscured glass globe in scattering light in all directions is that the polar curve tends to become a circle. The progressive effect of acid etched, sand blasted, and



Lightly ground glass
(Unsatisfactory diffusion.)



Opal glass
(Satisfactory diffusion.)



Prismatic glass
(Satisfactory diffusion.)

FIG. 107. Illustrating the difference between good and imperfect diffusion from globes.

With a lightly ground surface an image of the source can be seen through the glass owing to some light being transmitted direct.

opal globes on the polar curve of an ordinary tungsten lamp is clearly shown in fig. 108, which was presented by Messrs Clark and Mackinney in the paper referred to previously.

An opal globe very nearly changes the curve into a circle, while the effect of an acid etched globe is relatively slight. A bare tungsten filament emits very little light immediately under the lamp, and the use of an opal globe leads to an improvement in this respect. But it is evident that even in favourable circumstances quite half the light will be expended above the

horizontal, whereas in practice the light is usually required in the lower hemisphere.

The diffusing glass globes ordinarily used with arc lamps for street lighting have thus the drawback of sending an unduly large amount of light upwards. Some interesting experiments on globes having a progressively graduated capacity, varying at different angles, were recently described by Messrs S. L. Pearce and Ratcliffe;[1] but it would seem that the possible gain in efficiency through this device is not large, and that, in order to improve the distribution very materially, it would be necessary either to use a concentrating reflector above the lamp or to employ prismatic glass. A prismatic globe has one distinct advantage over those made of glass that have merely a scattering effect. By suitably shaping the prisms a directive effect can be introduced, and a considerable proportion of the light concentrated in the lower hemisphere; but even by this means one cannot readily secure a focussing effect comparable with that obtained from the best prismatic glass reflectors. As an illustration we may take the Holophane globes. Such globes were designed about thirty years ago by Mr A. P. Trotter in this country, and pioneering work on prismatic glass was also carried out by Blondel and Psaroudaki in Paris. The idea was subsequently developed with considerable enterprise and pertinacity by the Holophane Company in the United States. One essential characteristic of these globes is the use of a series of internal prisms, which break up and scatter the light in the manner shown in fig. 109, *a*. Their action may be compared with that of the rose on a watering-can, by which a powerful jet of water is broken into spray. In the same way the prisms scatter and soften the light and render it agreeable to the eyes.

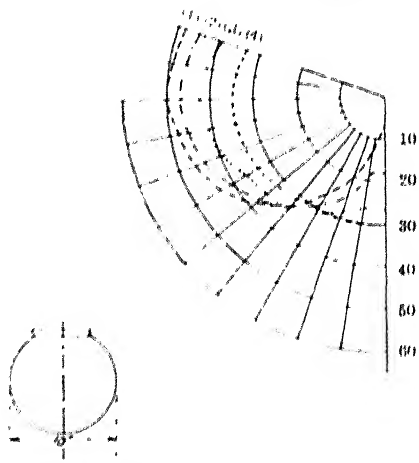
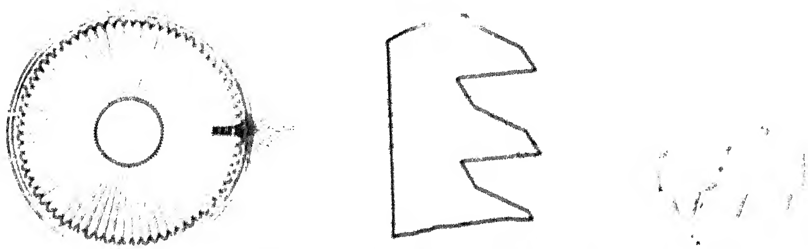


FIG. 108.—Distribution from (1) bare lamp, and same lamp in (2) acid-etched, (3) sand-blasted, and (4) opal globes respectively.

[1] Paper read before the Inst. Elec. Engineers, London, March 6, 1913.

There are also external prisms, whose function it is to direct the rays, both by refraction and reflection, in the manner shown in fig. 109, *b*. By giving these prisms the correct angle it is possible to secure, firstly, that a convenient percentage of the light is directed downwards, and, secondly, that the globe appears to the eye to be uniformly illuminated all over. In addition, the fact that the rays of light are merely diverted by clear glass surfaces, instead of being blocked by minute particles in suspension in the glass, leads to a low absorption.

The directive element can also be introduced by making the sphere in two sections, the lower one having prisms of the type described above, the upper half equipped with prisms so



(*a*) Scattering effect of internal prisms in a Holophane globe.

(*b*) Action of the external prisms in deflecting the rays and concentrating a certain percentage of the light downwards.

(*c*) Enlarged view of internal prisms and method of diffusing light.

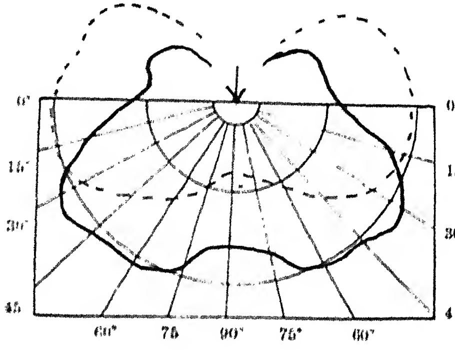
Fig. 109.

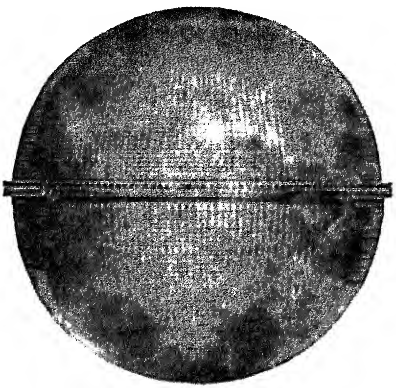
arranged as to reflect the rays downwards. In the reflector bowl an ordinary Holophane reflector (of the type to be described shortly) is used for the upper portion, and by this means the light in the lower hemisphere can also be strengthened (see fig. 110). Various forms of prismatic inner globes have been designed for use with arc lamps in street lighting. These we shall deal with in another section.

There are various methods of combining Holophane reflectors with frosted or milky glass hemispheres. Such appliances can be classed with globes in the sense that the source is completely enclosed, but it will be observed that the directive element is due to the introduction of a reflector.

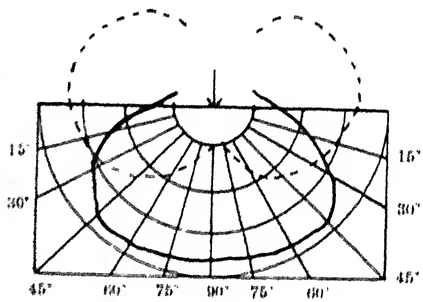
It is difficult to state the amount of light absorbed by typical glass globes with great exactitude. An accurate estimate of the light absorbed requires a measurement of the mean sph. c.p. of the source, first without and then with the globe. A mere determination of the light absorbed by a specimen plate of the

Small Holophane globe

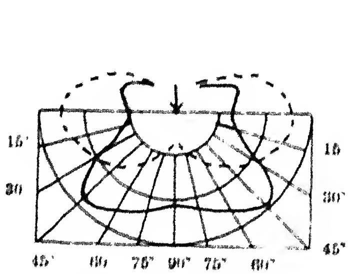




Large Holophane sphere



Holophane reflector bowl.



The full line shows the distribution curve from the fixture, the dotted line the curve from a bare lamp.

FIG. 110.—Showing distribution of light from Holophane globe, sphere, and reflector bowl.

glass used does not suffice. Even when the mean sph. c.p. is obtained there is a possibility that the physical condition of the source, and the light emitted by it, may be affected by the fact of its being enclosed. It is conceivable that this difficulty might be experienced with some electrical illuminants, and in the case of gas lamps its influence is well known. Thus A. Blok[1] mentions the case of a mantle whose candle-power was actually *increased* by enclosing it in a glass globe. It is also probable that the absorption varies somewhat according to the colour of the light, and media consisting of small suspended particles usually transmit the red end of the spectrum most readily.

Speaking generally, the percentage absorption may range from 10 to 50 per cent., according to the density of the glass employed, and it is even possible that the latter figures may be considerably exceeded in the case of globes that have become soiled with use, or encrusted with dust and dirt, or corroded by the fumes from the illuminant.

One finds considerable differences of opinion on these questions. For example, Prof. Marchant, referring to some tests undertaken by Prof. J. T. Morris, stated that he had met clear glass globes absorbing as much as 30 per cent.,[2] and that tests on opaline globes had yielded such figures as 57 per cent. and 68 per cent. On the other hand, Mr A. Denman Jones expressed the view that there should be no practical difficulty in securing a globe of good diffusing power absorbing only 20 per cent.[3] It appears too that various writers have adopted somewhat different definitions of absorbing power, and that the terms used to describe varieties in glass have not always been consistent. There seems a need for a comprehensive series of tests on modern globes.

The table on opposite page will serve to show the figures most generally presented.

Many lanterns having square panes of glass achieve substantially the same results as globes, but there is not, at present, much to say about their design from the illuminating engineering standpoint. Attention has hitherto been concentrated mainly on their mechanical details (*e.g.* on rendering them rain- and wind-proof).

[1] *Illum. Eng.*, London, vol. vi., Aug. 1913, p. 420.
[2] *Ibid.*, vol. i., 1908, p. 870. [3] *Ibid.*, p. 958.

ABSORPTION OF GLOBES.

Authority.	Type of Globe.	Absorption.
Prof. J. T. Morris and E. G. Farrow (*Illum. Eng.*, London, vol. i., 1908, p. 985)	Clear glass	14·8 per cent.
	Slightly opalescent	23·8 ,,
	Small opal	17·2 ,,
	Large ,,	31·7 ,,
B. Monasch (*Elektrische Beleuchtung*, p. 171)	Clear glass	5–15 ,,
	Opal ,,	10–35 ,,
	Alabaster glass	20–50 ,,
Prof. W. Barrows (*Elec. Illum. Eng.*, p. 2)	Clear glass	5–12 ,,
	Light sand blasted glass	10–20 ,,
	Alabaster glass	10–20 ,,
	Ribbed glass	15–30 ,,
	Opaline ,,	15–40 ,,
	Ground ,,	20–30 ,,
	Medium opalescent	25–40 ,,
	Heavy ,,	30–60 ,,

MATERIALS AND DESIGN OF SHADES AND REFLECTORS.

In selecting a reflector one of the first points to be considered is whether an opaque or translucent material is preferable. As a rule opaque reflectors, completely concealing the source, are preferable for local illumination, when the lamp may be placed quite near the head of the worker.

For general illumination, on the other hand, a translucent reflector which transmits a certain amount of light is usually preferable, as the upper portion of the room would otherwise appear unduly dark.

The chief materials used for opaque shades are cardboard and metal (polished, semi matt, or enamelled). The translucent materials include acid-etched, sand-blasted, prismatic, and milky glass of various descriptions. Mirrored glass is largely used for reflectors of a concentrating type, such as those used for automobile headlights. Silk and paper are valuable for decorative purposes, but have little directive power and are not much used for industrial illumination. Voege has recently recommended the use of marble.[1]

The advantages of cardboard are its lightness and cheapness. Cardboard shades can be readily attached to an electric lamp-

[1] *Elektrot. Zeitschr.*, 19th Feb. 1914, pp. 199–203.

holder without a heavy carrier. The reflecting qualities of a good white cardboard are excellent for certain purposes, and shades of this kind are still almost invariably used for billiard table lighting. On the other hand, the surface darkens with age, so that the shades require occasional cleaning or renewal; and the price at which they are supplied does not admit of much artistic treatment or special design. The conical shape is almost invariably used. Experiments have occasionally been made with aluminium coated cardboard surfaces, but they do not appear to have "caught on" to any extent.

The recent tendency towards the use of high candle power sources suggests that there are still possibilities in the use of such materials as papier mâché for large reflectors. It might be desirable, in lighting large halls, etc., to use hemispheres or hoods of considerable size, the white interior of which could be lighted indirectly by groups of high candle power lamps or covered over by some translucent diffusing paper. Very large units of this kind would probably be too weighty if constructed of glass or metal, but it is conceivable that some form of pressed cardboard or paper could be effectively employed.

For industrial lighting metal reflectors have a field of their own. For this purpose materials which are not readily broken or tarnished and can be readily cleaned are desirable. As a very large section of industrial illumination is carried out on the local principle, and it is not considered necessary to allot much light to the upper part of the room, the fact of the metal being opaque is no great drawback. Moreover, the reflecting quality of the surface of steel reflectors can be readily varied. By the use of white enamel an approximately matt diffusing surface, which is easily cleaned, can be obtained. A highly polished metal surface, on the other hand, facilitates the concentration of light. It is also possible, by means of aluminium or similar rough finish, to get an effect intermediate between polished and matt reflection.

But it is when we come to translucent materials, such as glass, that the greatest possibilities of scientific treatment reveal themselves. The surface of glass can be treated in so many different ways—ribbed, acid etched, sand blasted, etc.; the nature of the glass, its colour, opacity, and refractive index can be varied between wide limits; and the possibilities in the refraction and reflection of light by prismatic design are infinite.

A distinction may be drawn at the outset between "white glass" reflectors (opal, alabaster, alba, etc.) and those made of

clear glass in which reflection and refraction from prisms is employed. The ordinary shallow, opal shade, it has already been pointed out, bears little evidence of scientific design, and is neither beautiful nor effective from the utilitarian standpoint. But during the last few years considerable advances in the manufacture of white glass reflectors have been made, and there are now available types constructed on much more rational principles. As an illustration of these we may take the Veluria reflectors introduced in England by the British Thomson-Houston Co., one of which is shown in fig 111.

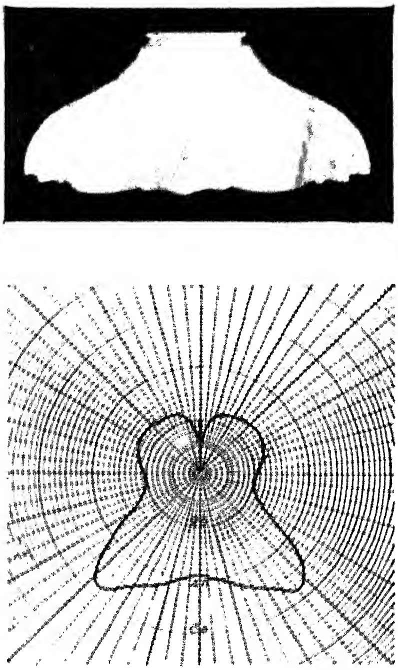
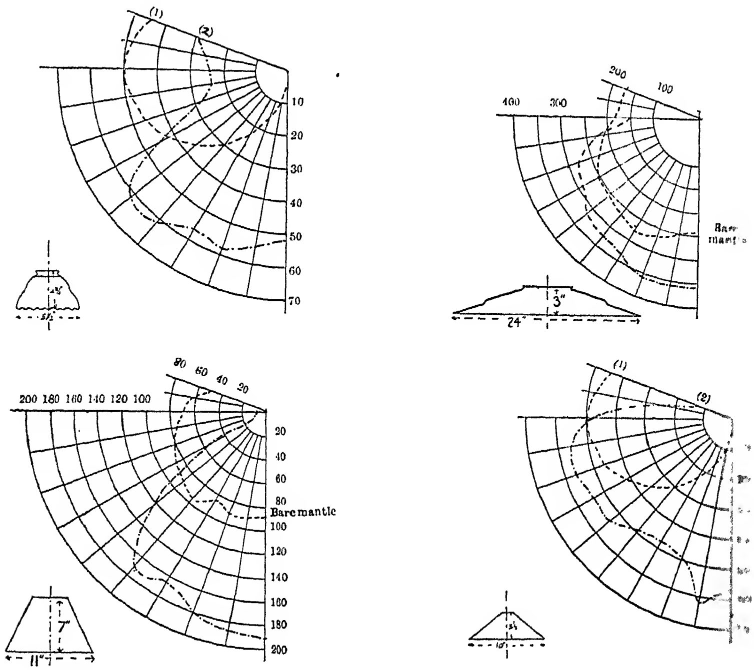


FIG. 111.—Veluria (B.T.H.) reflector and corresponding polar curve of light distribution.

Opal glass shades have also been widely used in the gas industry. In figs. 112A, B, C, and D we reproduce some data on such shades, taken from the paper read before the Illuminating Engineering Society in 1913 by Messrs J. G. Clark and V. H. Mackinney.

In the case of the majority of white glass reflectors we have to deal with a mixture of direct and diffused reflection. For example, in the ordinary opal shade we get direct reflection from the superficial glaze on the surface. A certain amount of light enters among the finely suspended white particles in the glass beneath this glaze. Part of this light is transmitted, but a considerable portion is also reflected diffusely. Direct reflection from polished surfaces has one drawback—it is apt to reproduce any striations in the light due to imperfections in the glass of a lamp-bulb or chimney. In some cases the polished surface of the reflector is therefore fluted or provided with concentric rippled rings in order to overcome this defect. A dead matt-white surface, on the other hand, tends to suppress streakiness. Yet it is usually essential to make use of a certain amount of polished reflection in order to get strong concentration of the

light. A matt reflector has comparatively little focussing power. Another point to be noted is that the absorption of a dead matt reflector will, in general, be greater than that of a corresponding polished one. For a great proportion of the reflected rays necessarily re-enter and strike the reflecting surface again; and at each successive reflection a little light is lost. There is also the difficulty that matt surfaces in general tend to collect dirt and become soiled sooner than polished ones.



FIGS. 112A, B, C, and D.—Distribution of light from typical glass reflectors (Clark and Mackinney).

In the ordinary clear glass prismatic reflector of the Holophane type advantage is taken of total internal reflection from a series of specially shaped right-angle prisms (see fig. 113). In the very early forms of Holophane globes only refraction was employed, and the concentrating power in this case was small. But by applying the principle of total internal reflection in connection with reflectors an entirely new field was opened up, and an immense range in distribution of light became possible. In general the prisms are on the outer side of the reflector, the inner surface being left plain. In this case the reflection

entirely direct, and yet the light is so broken up by the prisms that "striations" in the light are to a great extent smoothed away. The focussing power of such a series of prisms is remarkable, and permits considerable latitude in design of the shape of the reflector. Moreover, the absorption of light during reflection from a polished glass surface is remarkably small, even when a considerable proportion of the total flux of light is enclosed. In typical reflectors of the Holophane type the loss of light is estimated not to exceed 5 per cent. They are usually designed to transmit about 25 per cent. of the total light into the upper hemisphere, this being the amount of light considered desirable to allot to the upper part of the average interior. The remainder of the light is distributed in the lower hemisphere in various ways, according to the arrangement of the prisms and the purpose for which the reflector is intended.

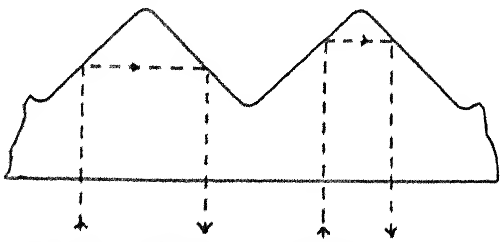


Fig. 113. Total internal reflection from a series of prisms.

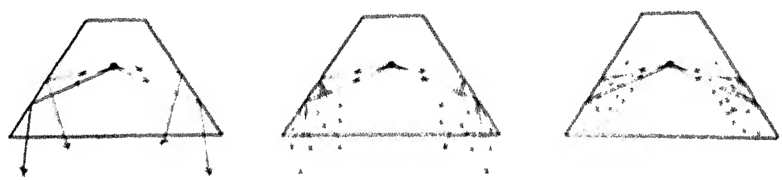
At this stage it may be well to point out some of the factors on which the successful design of a reflector depends.

In general the designer has to balance a number of distinct considerations. He must aim at a pleasing shape, and yet scheme the contour out in such a way as to get the desired distribution curve. He must arrange the unit so that the source of light will be, as far as possible, screened from direct vision; and yet he must not enclose the source more completely than is necessary, since the greater the proportion of the light flux intercepted, the greater the absorption of light is apt to be. The designer should also ensure that the illuminated surface of the unit will not appear "spotty," but uniformly light or at least that the gradation in brightness is not too abrupt.

Broadly speaking, the nature of the reflection will be one of three types shown in fig. 114, *i.e.* pure direct reflection, approximately pure diffused reflection, or a mixture of direct and diffused reflection. It is possible to calculate the effect of polished reflection with some precision, and it is also possible to estimate the defect of the diffused deflection by considering the projected area of the surface of the reflector when viewed at

different angles. But it is usually preferable to supplement such calculations by tests on a small portion of the surface proposed; indeed, when a mixture of direct and diffused reflection occurs this is usually necessary.

A word or two may be said as to the amount of light absorbed by reflectors. In making comparisons on this point some judgment is needed. For example, attention should be paid to the percentage of the total flux of light enclosed. A very shallow type of unit, which allows practically all the light to stream out unaffected naturally absorbs very little light, but it may nevertheless be a very bad reflector. For example, it may not screen the source sufficiently to avoid glare and may allow too much light to escape out horizontally. On the other hand,



(a) Direct reflection. (b) Mixture of direct and diffused reflection. (c) Diffused reflection.

FIG. 114. Illustrating distinction between direct (polished) reflection, diffused reflection, and a mixture of direct and diffused reflection from the surface of a shade.

dense tinted shades, almost completely screening the source, frequently absorb a great deal of light without giving any compensating advantage.

A noticeable difference in the amount of light absorbed by a reflector may occur, according as clear glass or obscured glass bulbs or chimneys are used. In such cases much of the reflected light re-enters the obscured area; this causes an added absorption, that is not, strictly speaking, due to the action of the reflector itself. It must also be remembered that scientifically designed reflectors in general give the best results with the type of lamp for which they are designed. For example, the use of an electric lamp with a filament having dimensions quite different from those characteristic of the type of lamp recommended, may cause some disturbance of the proper functions of the unit.

It seems probable that the absorption of light by a well-designed reflector should not as a rule exceed 10 to 15 per cent., and in some cases, e.g. in the Holophane reflectors, it is credibly stated to be very much less.

Illuminating Engineering Calculations and the Spacing of Globes and Reflectors.

In order to illustrate the value of scientific data regarding the action of globes and reflectors, some account may next be given of the calculations most frequently used in illuminating engineering. Only a few years ago the installation of lighting units was habitually carried out on a purely "rule of thumb" basis. It was customary to prescribe a certain number of lamps for a room of given size, but little attention was paid to the effect of the shades and reflectors used with such lamps, and the intensity and uniformity of the resultant illumination was not closely studied.

At the present time the tendency is towards more scientific methods. Lighting engineers endeavour to form an idea of how much illumination is needed in a room devoted to a specific purpose, and to work out beforehand how the lamps should be placed, and what type of shades or reflectors should be used, in order to obtain just the illumination required.

Illuminating engineering calculations offer a very fascinating field for theoretical study, and a great deal has been written on this subject. Special reference might be made to the exhaustive treatment of the subject in the works of Trotter,[1] Bloch,[2] Hogner,[3] and others; and Bertelsmann[4] has compiled a very serviceable book of reference tables. Readers may also with advantage consult the series of references given at the end of a lecture by Prof. W. E. Barrows at the Johns Hopkins University, Baltimore, in 1910. A paper on this subject was read before the Illuminating Engineering Society (London) by Mr W. C. Clinton in 1914, in which the illumination in a series of installations was calculated in detail.[5] It was shown that quite satisfactory agreement between observed and calculated values could be obtained—a valuable conclusion which justified the care with which each step in the proceedings was worked out.

It is very useful for the illuminating engineer to have at his command methods of solving even the most complicated problems. In dealing with novel installations, where there is little past experience to fall back upon, it may be necessary to calculate out the conditions from first principles. But in

[1] *Illumination, its Distribution and Measurement*, pp. 25–64.
[2] *The Science of Illumination* (translated by Prof. W. C. Clinton).
[3] *Light, Radiation, and Illumination* (translated by Justus Eck).
[4] *Rechentafeln für Beleuchtungstechniker.*
[5] *Illum. Eng.*, London, April 1914, p. 189.

ordinary practice it is usually necessary to avoid very elaborate calculations and to use approximate time-saving devices as far as possible. We do not therefore propose to enter very deeply into this subject, but only give an idea how the data used in the average installation are derived.

The most frequent and simplest calculation met with in illuminating engineering is the determination of the normal illumination received underneath a lamp hung at a certain height. Take, for example, a 16-c.p. lamp in a Holophane "I" type reflector hung about four feet above a table. Referring to the polar curve of such a unit, we see that the intensity immediately under the lamp is about 35 c.p.—rather more than double the horizontal candle-power of the electric lamp. The illumination on the table immediately under the lamp will therefore be $\frac{35}{(4)^2} = 2{\cdot}2$ foot-candles (approx.), which is sufficient for ordinary reading purposes.

In the same way the normal illumination, at a given distance in any desired direction, can easily be calculated by reference to the polar curve of the source, and by using the inverse square law. For example, with the unit mentioned the normal illumination received at a distance of 5 feet, and at an angle with the horizontal of 45°, would be $\frac{30}{(5)^2} = 1{\cdot}2$ foot-candles.

The question may arise whether sources equipped with highly concentrating reflectors obey this law strictly. The inverse square law may not apply rigidly to mirrored reflectors of the searchlight type, but in the case of the vast majority of units employed for ordinary purposes of illumination it does so quite sufficiently accurately for practical purposes.

The next step is to calculate out the horizontal illumination at any distance from the foot of a lamp, hung at a certain height. Imagine a source, hung at a height h. Consider the illumination derived from a ray I_θ, making an angle θ with the vertical. The normal illumination E_n, at a distance r feet, and at a short distance from the point immediately under the lamp, will be $\frac{I_\theta}{r^2}$. To obtain the corresponding horizontal illumination I_h, we must multiply by the cosine of the angle of incidence (which is equal to θ). Now $\cos\theta = \frac{h}{r}$.

$$\text{Hence} \quad E_h = \frac{I_\theta}{r^2}\cos\theta = \frac{I_\theta \cos^3\theta}{h^2}.$$

In order to obtain the horizontal illumination at any point it is therefore only necessary to multiply the value of the illumination immediately under the lamp by the corresponding value of $\cos^3\theta$. Curves and tables giving the value corresponding with lamps hung at various heights are much used by illuminating engineers; and many companies, besides giving the polar curves of their lighting units, provide diagrams showing the horizontal illumination derived when these lamps are hung at the customary height.

The Welsbach Co. of New Jersey, U.S.A., in their *Illumination Data Book*, follow the admirable method of reproducing

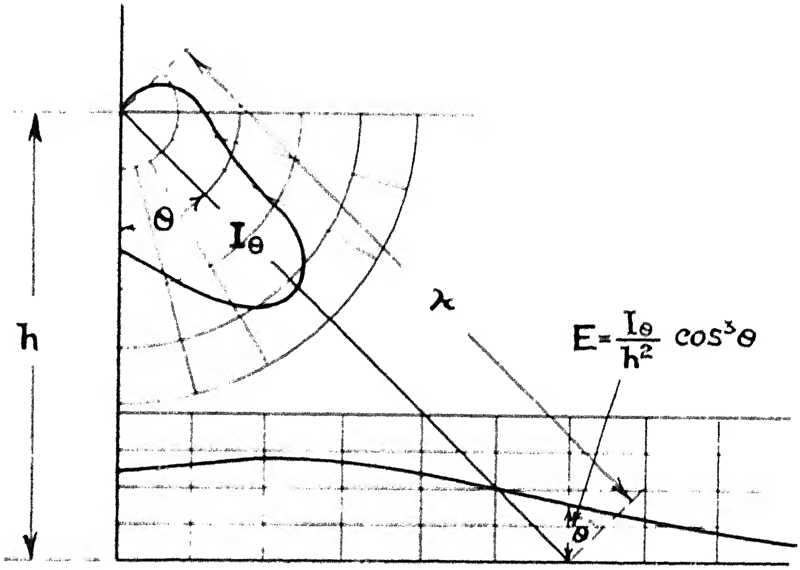


FIG. 115.—Showing how the horizontal illumination $E = \frac{I_\theta}{h^2} \cos^3\theta$, is derived from a source having a known polar curve and an intensity I_θ at an angle θ.

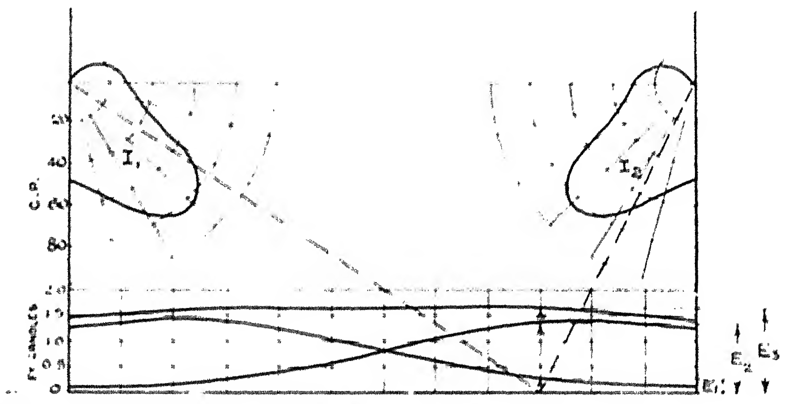


FIG. 116.—Showing how the separate illuminations E_1, E_2, due to two sources of the type shown in fig. 115, can be added together so as to obtain the total illumination E_3. In this case the sources are so spaced as to give approximately even illumination between them.

side by side photographs of the various units and records of the distribution of light derived from them. A similar plan has always been adopted in connection with the Holophane literature.

In figs. 115, 116 we reproduce a typical polar curve and the derived diagrams of horizontal illumination from two lamps at a specified distance apart. By adding up the illumination due to each lamp we obtain a third curve showing the total illumination due to the two. Such curves are of considerable importance in connection with street lighting, where the aim of the engineer is to adjust the distance and the nature of the polar curve so as to make the illumination between the lamps as uniform as possible.

It is becoming customary for manufacturers to standardise the data for their units, and to recommend spacing rules applying to such sources hung at the customary height. There are various methods of arranging lamps to give uniform illumination. In a high and narrow passage it is usual to arrange the sources in a central line, the intervals being selected in the manner described above. Occasionally lamps are staggered in the form of a triangle, but the most usual method, which is particularly applicable to large areas, is to space the points in squares. The distance between each pair of lamps along the side of a square is selected to give uniform illumination, and will naturally vary according to the height at which the lamps are hung and the nature of the polar curve. With a well-designed unit the illumination on the working plane should be practically constant; for example, the value at the centre of the square should be practically identical with that along its edges.

The system has been very thoroughly worked out by the Holophane Co., whose reflectors are made in three distinct types—E (extensive), I (intensive), and F (focussing).

The "E" type of unit is used mainly for small rooms with one central point, for large rooms with low ceilings, and for corridors. The effect of these reflectors is to direct a considerable portion of the light in the upper region of the lower hemisphere, the maximum intensity being located near 45°. Consequently such reflectors are best used for providing general illumination, rather than for concentrating the light over a narrow area; they are spaced comparatively far apart.

The "I" type of unit is intermediate between the "E" and "F" reflectors. A comparison of its polar curve with that of the "E" type reflector (see fig. 117) shows that the majority of the light is concentrated fairly evenly over an angle of 90°, the values at 45° and immediately below the lamp being very nearly the same. This type is very usually employed for lighting isolated desks and tables, and fairly lofty rooms.

The "F" type of unit is designed with a view to concentrating the light over a small area. It is therefore most valuable in cases where a strong local illumination is necessary, and for large and lofty rooms where the units are conveniently hung high up.

The decision which of these three types of reflectors should be used in an installation call for some judgment. For example, the use of "E" type reflectors at a considerable height from the floor and in a small but lofty room would probably result in an excessive amount of light being thrown on the walls, and an unduly low illumination down below. Again, if "F" type reflectors were used, but spaced at intervals intended for "E" type units, the illumination on the floor would be spotty, *i.e.* very strong in some parts but too weak in others.

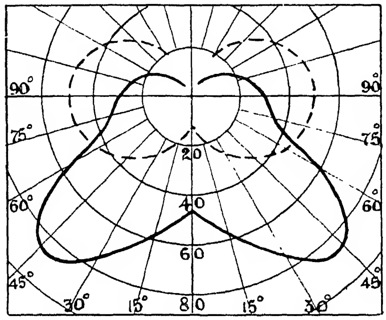
In order to ensure uniform illumination and the best conditions generally, the following spacing rules are therefore given.

"E" type units should be spaced at a distance apart equal to twice their height.
"I" type units should be spaced at a distance apart equal to one and a half times their height.
"F" type units should be spaced at a distance apart equal to their height.

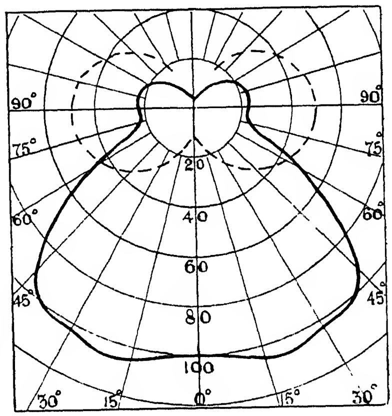
The essence of these rules is tabulated in fig. 118. It will be observed that although the illumination is evenly distributed in each case, the consumption of energy for a given area for lamps of a given wattage and the amount of illumination on the working plane increase, progressing as we proceed from the "E" to the "F" type, so that in general lamps of smaller candle-power will suffice with focussing reflectors. A comparison of the three typical polar curves with that of a bare lamp (shown dotted) shows very clearly the great practical utility of a well-designed reflector (especially in the case of the electric metal-filament lamp, which throws such a comparative small proportion of light downwards).

It should be mentioned that these calculations are based solely on the *direct* light. In general the illumination will be in excess of that specified, owing to the reflection of a certain amount of light from walls and ceiling. As a rule lighting engineers prefer not to count on such extra illumination in their calculations, since it is naturally a somewhat variable element, depending on the size of the room, and the distribution of light

Extensive ("E" type) Holophane reflector.



Intensive ("I" type) Holophane reflector.



Focussing ("F" type) Holophane reflector.

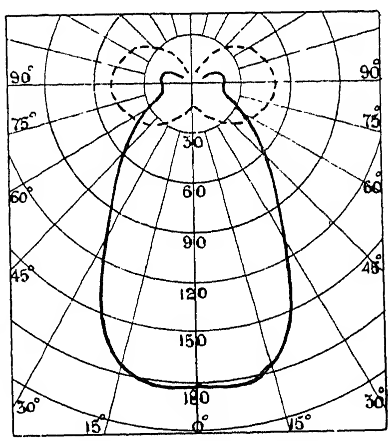
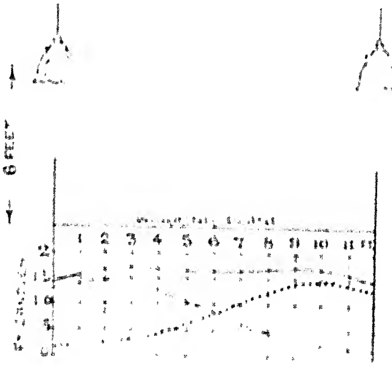


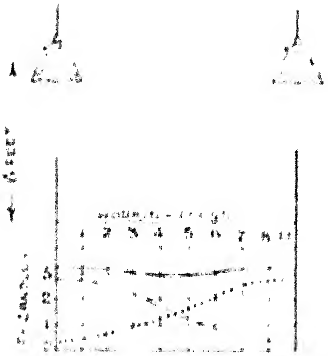
FIG. 117.—Holophane "E," "I," and "F" reflectors and corresponding polar curves.



Holophane "E" type reflectors.

Spaced a distance apart equal to *twice their height* in order to give even illumination.

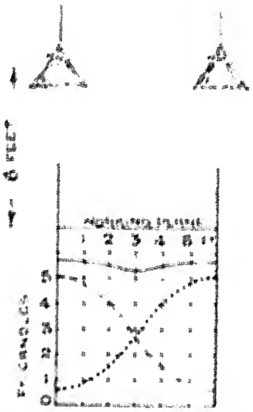
Illumination from 50-c.p. lamps, 6 feet high, approx. 1·5 *foot-candles.*



Holophane "I" type reflectors.

Spaced a distance apart equal to *one and a half times their height* in order to give even illumination.

Illumination from 50-c.p. lamps, 6 feet high, approx. 3 *foot-candles.*



Holophane "F" type reflectors.

Spaced a distance apart *equal to their height* in order to give even illumination.

Illumination from 50-c.p. lamps, 6 feet high, approx. 5½ *foot-candles.*

N.B.—*In these data the effect of reflection from walls and ceilings is not included.*

FIG. 118.—Approximate spacing for holophane reflectors shown on left, and illumination derived therefrom.

from the reflectors, as well as the tint of the walls and ceiling. But an engineer who is familiar with a certain system of illumination can often form at sight a surprisingly close estimate of what the effect of reflection in a given interior will be, and make use of this in his calculations.

The "E," "I," and "F" system and the derived spacing rules have been applied to various types of reflectors; for example, to the Benjamin steel reflectors. It is naturally a decided advantage to have such data: and a drawback in the eyes of a consulting engineer when he finds that, if he installs a certain type of unit, there is no available information by the aid of which to estimate the illumination to be obtained.

There are, of course, many cases in which it is impossible to apply such rules exactly. For example, it may be required to install reflectors not in their ideal positions, but where the existing outlets are located in a room. It is then necessary to make the best compromise, and a combination of "E" and "I" reflectors is sometimes desirable. There are also cases in which a strictly even illumination is not wanted, and special arrangements have to be made to concentrate the light at particular points.

Again, in the lighting of streets and large open spaces it is often impossible, owing to limitations imposed by cost, etc., to secure even approximately uniform lighting. A great deal has been written on the calculation of illumination in these circumstances. To determine the combined effect of a number of sources is a decidedly complicated problem.

Engineers often find it preferable to fall back on data previously obtained by illumination measurements in similar circumstances, rather than to work out the values from first principles. Those interested in this problem, and particularly in methods of calculated mean illumination over large areas, may be referred to some constructions suggested by Högner (*loc. cit.*).

There are two chief methods of representing the distribution of illumination graphically. We may construct "contour lines," in the manner favoured by Mr A. P. Trotter (*loc. cit.*), or one may divide up the area into a number of small squares, and indicate on each the average illumination at that point. On plans of many interiors (school-rooms, libraries, etc.) it is often sufficient merely to mark the illumination at the chief points of interest, *e.g.* on the desks, tables, blackboards, etc.

Where an area has been subdivided into squares, and the illumination at each point either measured or calculated, the deter-

mination of the arithmetical mean value is a simple matter. It is, however, sometimes possible to estimate the mean illumination over an area straight from the polar curve of the illuminant to be used. For example, take the case of a lamp in a reflector suspended at a given height above a table. It is possible to ascertain from the polar curve the flux of light corresponding with the solid angle subtended by the table, and this, divided by the area of the table surface, gives the mean illumination at once. This method has sometimes been used in the case of large illuminated posters, and it has been proposed that in lighting a room from the centre we should allot a certain flux of light to the floor, walls, and ceiling, and select the polar curve accordingly. It has also been suggested that the "flux of light" method might be used with advantage in connection with street lighting, where the determination of the true mean illumination is often a difficult matter.

A special instance of the utility of these flux of light calculations is in connection with electric searchlights, for which Dr Louis Bell gives the following formula:—

The illuminaton E in foot candles $= \dfrac{4\pi ei\eta}{\pi r^2} = \dfrac{4ei\eta}{r^2}$,

where e = voltage of the arc;
i = current of the arc;
η = specific consumption in watts per mean sph. c.p. (this may usually be taken as 1);
r = radius of the beam of light where it impinges on the surface illuminated.

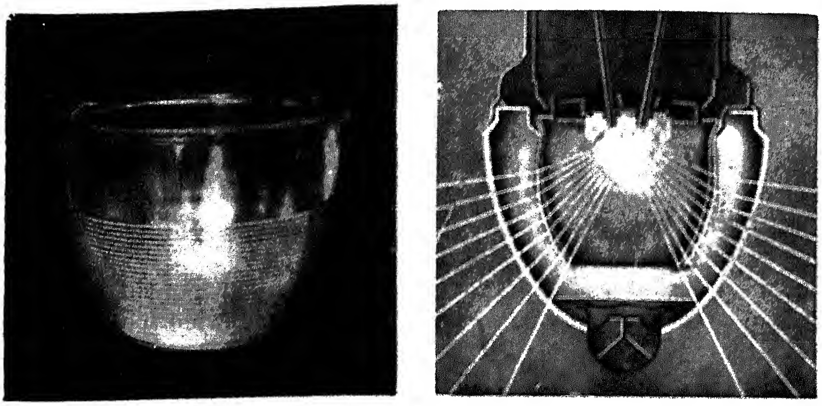
The quantity $4\pi ei\eta$ represents the flux of light from the searchlight and is perfectly definite; on the other hand, a searchlight has not, according to the accepted definition, a very well-defined candle-power.

GLOBES AND REFLECTORS FOR STREET LIGHTING.

Much remains to be done in connection with the scientific distribution of light by globes and reflectors in the streets. In the great majority of street lanterns such direction of light as occurs is achieved by a reflector placed above the source. This should be of enamelled iron or some material which is not readily corroded and easily cleaned.

At present these reflectors are almost always shallow and only screen the sources very slightly (if at all) from the eyes of passers-by. The extreme brilliancy of modern street-lighting

sources seems to call for a change in this respect. It is sometimes contended that lamps in the streets, being as a rule comparatively distant from the eye, should not cause much glare. But it must be remembered that the lamps are seen against a



(*a*) General view of globe.

(*b*) Showing how rays are bent by the prisms, altering the polar curve and improving the illumination midway between the lamps.

FIG. 119.—Dioptric inner globe used with Excello flame arc.

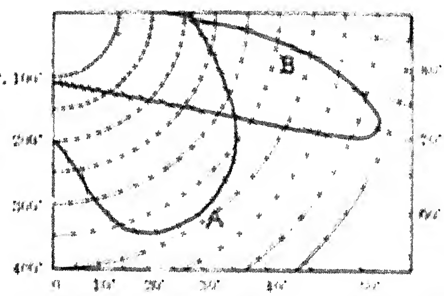


FIG. 119A.—Showing action of dioptric globe in strengthening the candle-power at angles slightly below the horizontal.

A. Polar curve of Union Excello flame arc (10 amp.) with clear glass globe.
B. Similar arc fitted with inner dioptric globe and clear glass outer globe.

much darker background than if they were used for interior lighting, and it is common experience that many of the street-lighting systems of the present day have a decidedly dazzling effect.

In the interests of traffic it may well be suggested that it would often be better to sacrifice uniformity of illumination to some extent, if this step is necessary, in order to avoid glare from powerful lamps.

There are now in use various devices designed to improve the distribution of light from street lamps. The well-known dioptric globe used with Excello lamps alters the polar curve of light distribution materially, as shown in fig. 119, and improves the diversity coefficient (ratio between the maximum and minimum illumination). This is illustrated in fig. 119A. Other apparatus has been devised with similar intent; for example, the Peard reflector,[1] which is placed below a focussing arc lamp and reflects some of the vertical rays which would otherwise illuminate the portions of the pavement nearest the lamp.

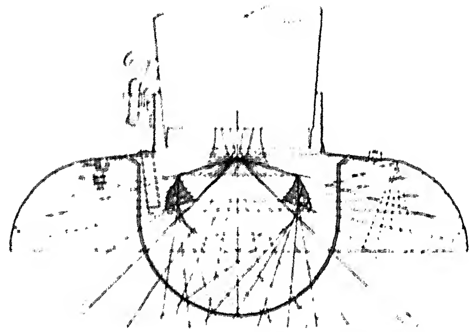


FIG. 120.—Hrabowski reflector for flame arcs.

Another device is the total reflector designed by Hrabowski,[2] which consists of enamelled metal portions, supplemented by an inner ring of clear glass (see fig. 120) which totally reflects a portion of the rays falling upon it. This reflector, by softening the light at small angles to the horizontal, is also intended to suppress glare. The rays between 45° and the vertical, which are not likely to enter the eyes direct, are allowed to pass unimpeded, but rays outside this angle are diffused by the reflector, and their glaring effect is lessened.

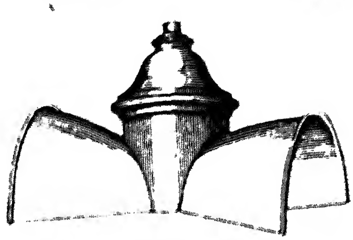


FIG. 121. The "Equilux" reflector (C. H. Sharp), designed to deflect the rays which would otherwise escape upwards and sideways along the street.

The "white way" system of lighting developed in the United States also deserves notice. In this method a number of tungsten filaments in appropriate globes are arranged at the top of an ornamental column. The subdivision of the light into small units, and the diffusing effects of these globes, doubtless does something to diminish the glare.

It will be observed that all the foregoing units are sym-

[1] *Electrician*, 1910, p. 365.

[2] *Elektrot. Zeitschr.*, 6th Jan. 1910, pp. 11–13.

metrical in the vertical plane. Dr C. H. Sharp[1] has carried out the directive idea still furthur in the "Equilux" reflector, which is shown in fig. 121.

It consists of two metal cups on either side of the lamp, which not only direct the ray of light downwards but "scoop" in and deflect down the street rays which would otherwise escape sideways and illuminate buildings.

At a spot where there are four cross-roads, a fitting having four such reflectors would be used. The design of these re-

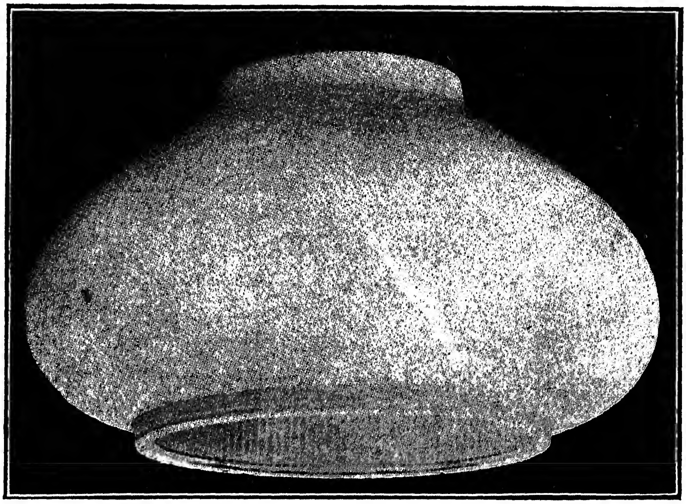


Fig. 122.—Combined prismatic and white glass reflector for street lighting (A. J. Sweet).

flectors is based on the assumption that the main object of a reflector is to illuminate the pavement and roadway, and that it is a mistake to allow any considerable portion of the rays to escape out sideways on to adjacent buildings.

There remains to be mentioned one interesting attempt, by Mr A. J. Sweet, to solve the problem of a unit for street lighting.[2] He advocates that the ratio of the height of the lamp-post to the distance between two adjacent sources should not be more than one to four; if the ratio much exceeds this value, it becomes more difficult both to secure uniformity and eliminate glare.

Sweet also came to the conclusion that light entering the

[1] *Trans. Illum. Eng. Soc. U.S.A.*, May 1910.
[2] *Jour. of the Franklin Institute*, May 1910.

eye at angles greater than 30° to the horizontal (the horizontal being the normal quality of vision of people walking down the street) is of relatively little consequence in causing glare, owing to the automatic screening effect of the human brow. He therefore devised a unit comprising an inner prismatic globe and an outer opal globe, used with a tungsten lamp. The nature of this will be understood from fig. 122. The outer opal reflector completely screens the rays from the eye within the prescribed angle, and yet the distribution curve is such as to enable practically uniform distribution of illumination between the lamps to be obtained. The success of this fixture seems to demand conditions as regards spacing which are not usually met with in street lighting, and this perhaps explains why it has not been widely used at present.

Indirect and Semi-indirect Lighting.

The increase in brilliancy of modern illuminants has stimulated interest in the so-called "indirect" system of lighting.

There are two chief methods of carrying this scheme into effect. In the so-called "cornice lighting" the lamps (usually tubular) are concealed beneath the white cornice of a room, and are usually arranged to illuminate a frieze. An instance of this style of lighting is afforded by the lecture-hall of the Institution of Electrical Engineers, London.

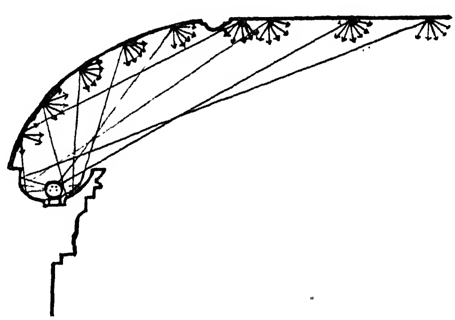


Fig. 123.—Sectional view of cornice lighting.

The light is concealed under the curved frieze, which it illuminates, the rays being diffusely reflected into the room.

Successful cornice lighting needs considerable judgment. A common defect is uneven illumination and "spottiness"; this is difficult to avoid when the lamps are placed near the wall. In rooms with low ceilings the brightly illuminated area is apt to come within the direct range of vision, and the display (notwithstanding its comparatively low brilliancy) of such a large illuminated area may give rise to a species of glare.

A better-known system of indirect lighting is by means of

lamps suspended in inverted bowls or hoods which serve to distribute the light evenly over the white ceiling. This method has been utilised in connection with arc lamps for a long time. It was also used occasionally in connection with carbon filament lamps, but in these circumstances was too expensive to be widely used. The coming of the tungsten lamp led to its revival with incandescent lighting, and under the name of "eye rest" system

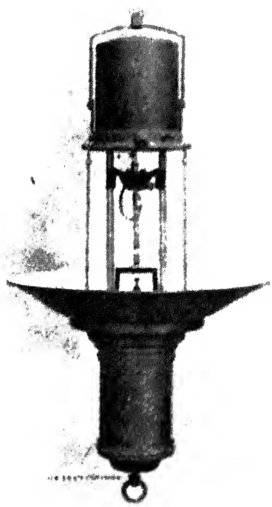


FIG. 124.—Typical inverted arc lamp (Union).

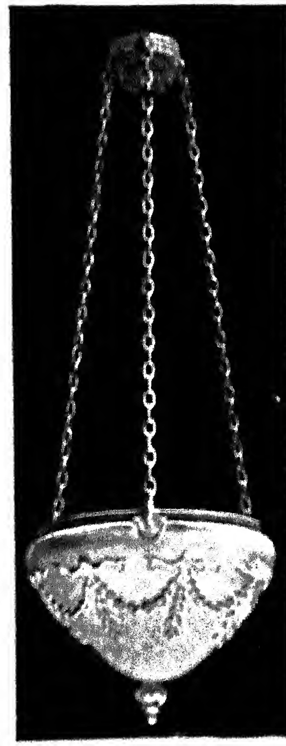


FIG. 125.—Indirect Adams fitting for tungsten lamp (B.T.H.)

it has been energetically taken up by the British Thomson-Houston Co. Indirect arc lighting ("eye comfort" system) has been made a special feature by the Union Electric Co. for some time.

Several recent papers and discussions have dealt somewhat fully with the merits of direct and indirect lighting[1] Regarded as a method of shading, indirect lighting fulfils completely the

[1] See F. W. Willcox, *Illum. Eng.*, London, vol. vi., Jan. 1913; T. W. Rolph, *Trans. Illum. Eng. Soc. U.S.A.*, Nov. 1912; T. W. Rolph, J. G. Henninger and S. G. Hibben, *Trans. Illum. Eng. Soc. U.S.A.*, June 1912.

function of screening the source from the eye and avoiding direct glare, thus giving what is called a "soft" light, and is conducive to very uniform illumination in the working plane. The diffusion from a white ceiling enables the light to penetrate to every corner of the room, and to enter into recesses, cupboards, pigeon-holes, etc., when direct light would cast a shadow. In certain classes of work, for example, in rooms occupied by intricate

FIG. 126. Indirect lighting in an office (B.T.H. "eye-rest" system).

machinery, this is a decided advantage. Again, the fact of the lighting coming from such a large area is influential in avoiding glare from polished surfaces and slightly glazed paper; the light is considered by many people to be very convenient for reading on this account. It has also been claimed that people working by indirect light are content with a lower reading illumination than is necessary with direct lighting. But it would appear that there is a division of opinion on this point, and there hardly seems sufficient evidence at present to pronounce one way or the other.

One of the chief limitations of indirect lighting, as usually practised, is its dependence on a good white ceiling. When the

surroundings are dingy and the ceiling is permanently composed of dark material, or pierced for sky lights, it is usually difficult to make successful use of the method with the present appliances. For industrial lighting it is possible to replace the ceiling by enamelled white reflectors, placed immediately over the lamp. This device appears at present to have been most successful with arc lamps. But it is obvious that the area on which the light is received must be much less in these circumstances so that the diffusion is not so complete and these large reflectors are apt to be unsightly.

Pure indirect lighting must naturally lead to a certain loss of light. There is a real loss of light in reflection from the ceiling, and there is also what may be described as an apparent loss of light due to the fact that a relatively large portion of the total flux of light is necessarily thrown on the upper portions of the room, compared with that directed on the working plane. In direct lighting, on the other hand, the concentration of the light is more completely under control, and the amount of light allotted to the walls and ceiling can be limited to that which is strictly necessary. In an up to date system of direct lighting with tungsten lamps it is practicable to secure a working illumination of 2 foot-candles with a consumption of about 0·5 watt per square foot. In cases where there is no need to expend any light on the upper part of the room, and highly concentrating opaque reflectors may be used, even more efficient results may be obtained. With pure indirect lighting and tungsten lamps, on the other hand, one usually finds that the illumination on the working plane does not exceed 1 foot-candle with the above expenditure; and to provide 2 foot-candles 0·8 to 1 watt per square foot would probably be needed. In favourable circumstances greater efficiency doubtless is possible, but in practice the consumption of electricity necessary with indirect lighting is usually about twice that required with the direct system.

In the case of indirect arc lighting, the higher efficiency of the arc light makes the loss of light of less consequence. In the majority of installations one obtains, with a consumption of 0·8 to 1·2 watts per square foot, an illumination of about 4 to 6 foot-candles: the "specific consumption" in watts per lumen is thus about the same as in good direct lighting.

One other point that needs to be borne in mind is that the efficiency of an indirect installation is apt to deteriorate as the walls and ceiling darken, as they do somewhat rapidly in the

grime of cities. A little foresight is therefore necessary on the part of the user, and periodic renovation of cleaning the reflecting surfaces should be encouraged. The effect of deposits of dust inside the inverted reflector used for indirect lighting must also be considered and demands some ingenuity in the design of such units.

An objection that has sometimes been raised to indirect lighting is based on the "shadowless" nature of the illumination. Now, the shadows thrown by an illuminated ceiling are naturally softer than those cast by small sources; but it appears incorrect to describe the system as "shadowless." It would only be possible to obtain complete absence of shadow in a room having white ceilings, walls, and floor, so as to resemble an Ulbricht globe. An interesting experiment on this point was described not long ago by Mr Justus Eck.[1] In order to demonstrate that indirect lighting was not shadowless, a white disc and sphere of the same diameter were hung side by side in a room lighted on this system. Photographs of these objects showed quite clearly that while the disc was evenly bright the sphere carried an unmistakable shadow. Measurements of the actual surface of the light and dark portions were taken, and the tone ratio was stated to be substantially the same as that met with in this room in daylight.

FIG. 147. Photograph of art room lighted by inverted arc (J. Eck).

The shadows on the statue are well marked. Above this are hung side by side a white disc and a white sphere. The shadow on the latter is quite evident, showing that this method of lighting is not "shadowless."

It would appear, however, that to many people the extremely soft shadows cast by some systems of indirect lighting appear unnatural, and that the effect of the bright ceiling and the

[1] *Electrician*, 26th May 1911.

absence of any apparent light source the sense of "something wanting" is sometimes disliked. People often complain of the monotonous effect of such installations. The question has been raised whether it is good for the eye to encounter constantly large areas of uniform brightness, and whether some measure of contrast is not essential to give occasional relief. Yet another

FIG. 128. Indirect lighting in the vestibule of a theatre (Milwaukee, U.S.A.).

complaint is that indirect lighting gives the impression of being "in a well," the room appearing unnaturally deep.

It is too early as yet to say how far such impressions have a definite physiological basis, and how far they are founded on mere caprice. Some of the defects referred to are mainly the result of faulty designs and are not inherent in the system. For example, when a number of these units are installed their height from the ceiling and distance apart requires careful adjustment to avoid "spottiness." The reflectors, again, should be so designed

as to avoid striations on the ceiling, and in the British Thomson-Houston X-ray mirrored glass surfaces concentric wavy rings are used to remove this defect. Another objection, that the bowls are apt to appear jet-black when seen silhouetted against the ceiling above them, can be met to a great extent by making the outer moulded surface of some light material; it is chiefly noticed when a single bowl is used, where there are a number of fixtures the surface of each bowl is illuminated by those around it. The "well effect," again, is accentuated by the use of very dark walls. On the other hand, an extensive area of very bright walls is apt to be trying to the eyes. It is possible that one might prescribe a definite ratio between the brightness of walls and ceilings that would give the best results. A ratio of about 5 : 1 has been suggested. Another point to be noted is that rooms containing a number of miscellaneous objects on the walls, and a fair amount of furniture on the floor, in general appear better by indirect light than those which are comparatively empty. The presence of such objects provides a little contrast and shadow and breaks up the monotonous effect. In many cases the provision of indirect general illumination, supplemented by suitable local lighting, gives good results. Indirect lighting seems at its best when the lighting arrangements are judiciously blended with the architectural features. For example, the use of an inverted bowl under a white dome usually gives a more pleasing effect than the spacing of a number of bowls under a flat white ceiling.

As an illustration of the successful combination of direct and indirect lighting in this way, we may mention the methods employed in many cinematograph theatres. A particularly good instance is the photograph of the West End Cinema Theatre in Coventry Street, London, shown in fig. 129. The dome in the ceiling is decorated in blue and gold and illuminated by amber lights mounted out of sight round the ring-cornice, and the panels round the room are also illuminated by concealed lamps. The lighting is pleasant and appropriate, and the use of the ring of amber lights round the dome gives a little variety and helps to remove any impression of "flatness" which might otherwise exist.

Indirect methods of lighting with gas have been comparatively seldom used in England. A few installations have been described in America, and the method has been tried with apparent success in some of the gas-lighted schools in Germany.

It seems probable that the semi-indirect system to which we shall next refer will be more favourably regarded by the gas industry.

SEMI-INDIRECT LIGHTING.

The system of "semi-indirect" lighting may be said to combine the advantages of the direct and entirely indirect systems, and seems likely to make a bold bid for popularity.

The chief characteristic of this system is the substitution of a translucent material instead of the opaque bowl, the surface being so designed that, while most of the light is still directed on the ceiling, a certain proportion is transmitted through the glass. An opal or frosted glass bowl is most commonly used, and by the use of suitably moulded alabaster (" Alba " and such like glass) a decidedly decorative effect may be obtained. The brightness of surfaces so illuminated is comparatively mild, so that they are pleasing to the eye. They should preferably be somewhat brighter than the ceiling.

One advantage of this system is that it removes the uncomfortable impression of "something missing" that is apt to be experienced when the source of light is completely concealed. The source of light is now evident, but its intrinsic brilliancy has been diminished to a more agreeable value, and the advantages of this widespread diffusion of light on the ceiling are still obtained.

The system should be more efficient than a purely indirect method. It is difficult to secure a reflecting power of more than 80 per cent. from polished metal or mirrored glass, but when translucent glass is used a great deal of the light which would otherwise be lost is transmitted, and if the right type of glass is used the absorption need not be high. Under favourable conditions the consumption of electricity should not exceed 0·3 to 0·35 watt per lumen (on the working plane). Little information is available as to the performances of semi-direct gas lighting units, but the comparison with direct lighting should be very similar, *i.e.* an increase in gas consumption of about 50 per cent. will probably be needed to secure the same illumination.

Another advantage of using a translucent bowl is that the brightness of the ceiling and walls can be made to shade off gradually. One avoids the hard line of division between brightness and shadow that is apt to be cast by an opaque reflector.

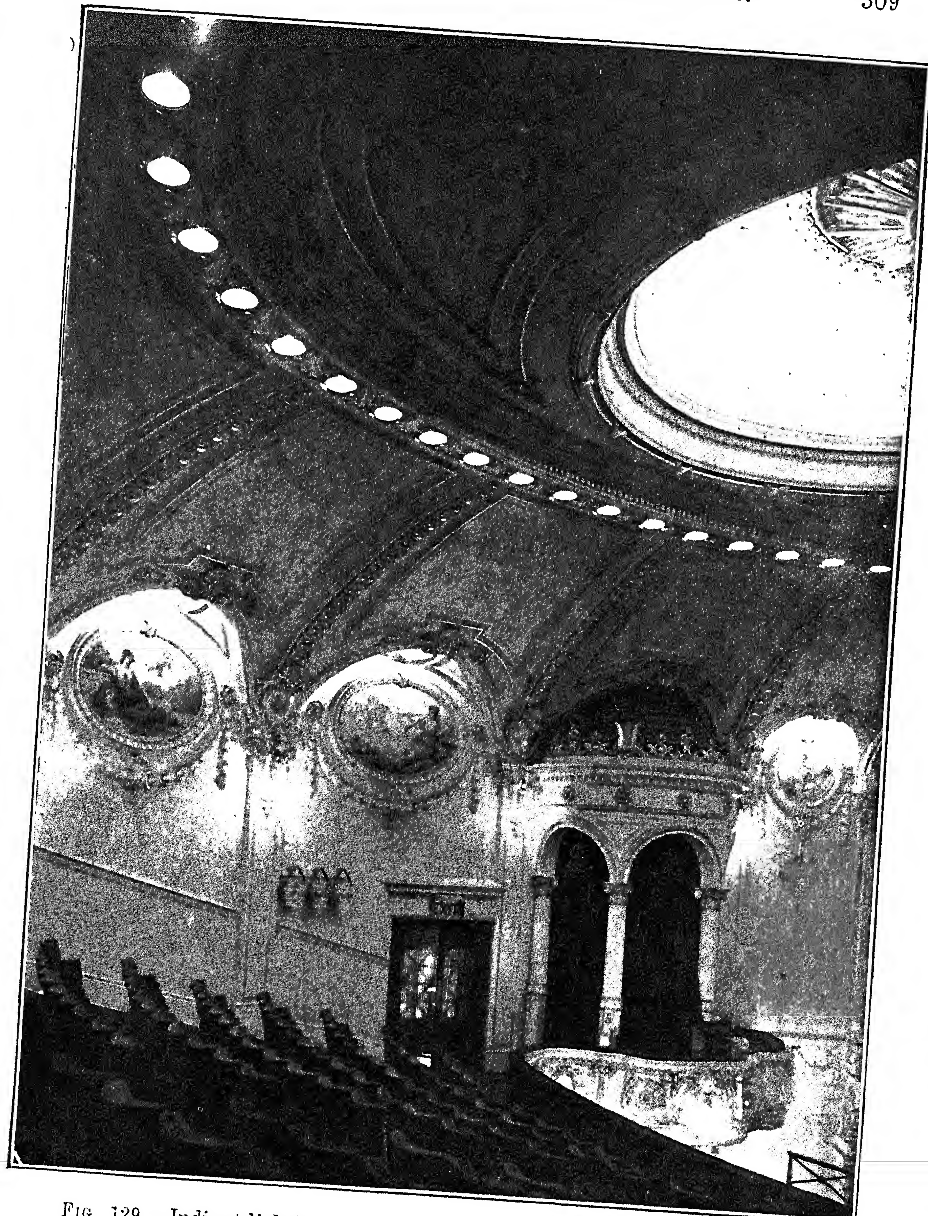


FIG 129 —Indirect lighting of the West End Cinema (Coventry Street, London).

The main illumination is derived from the central dome, decorated in blue and gold and illuminated by concealed lights, and from the ring of amber-coloured lamps behind diffusing-glass discs surrounding it. The panels are also lighted by concealed lamps.

In figs. 130–133 we reproduce some typical semi-indirect units. In most cases the under globe is made of some form of white glass. A number of units are now constructed having an

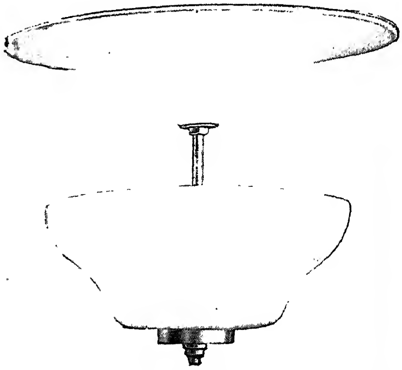


FIG. 130.—Semi-indirect unit for tungsten lamp (Benjamin Electric).

Some of the light is transmitted through the lower diffusing glass bowl. The remainder strikes the enamelled white reflector above, the actual filament being hidden.

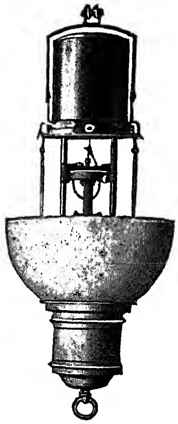


FIG. 131.—Typical semi-indirect arc lamp (Union).

Some of the light passes through the lower iffusing glass hemisphere, but the larger portion passes upwards to illuminate a white ceiling.

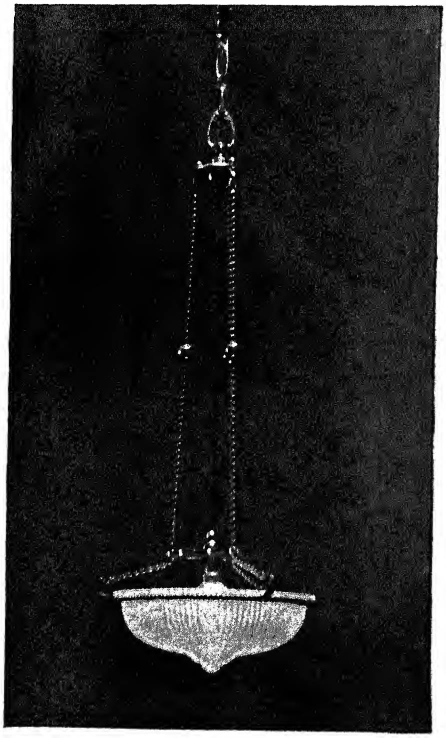


FIG. 132.—Holophane prismatic glass semi-indirect unit.

Approx. 75 per cent. of the light is directed upwards. The greater part of the remaining 25 per cent. is transmitted through the prismatic glass into the room.

upper white enamelled reflector, designed to receive and "spread" a certain portion of the light. When mounted direct on the ceiling this portion of the fitting is inconspicuous, but it is apt to give rise to unsightly shadows when hung some distance below it. The advantage claimed for these reflectors is that they

render the unit less dependent on the nature of the ceiling, though naturally a white surface is still a great advantage.

The Sugg semi-indirect fitting shown in fig. 133 is selected as an illustration of the application of semi-indirect lighting with gas. In appearance it is very similar to many electric units.

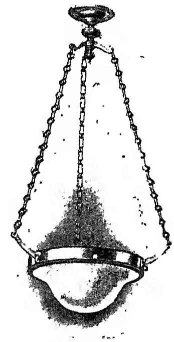


Fig. 133.—Sugg semi-indirect gas-lighting unit.

The gas is introduced by means of a flexible tube passing through one of the chains, and a second tube passing through another chain goes to the by-pass. The third chain may, if desired, carry a pneumatic tube or Telephos wire so as to enable the lamp to be controlled from a distance.

There has been some discussion as to the proportion of direct light that should be used in the semi-indirect system. The general view appears to be that at all events the greater part of the illumination should

Fig. 134.—Illumination of a drawing-room on the semi-indirect lighting system (Holophane unit.)

be indirect; otherwise much of the advantage of the system will be lost.[1] T. W. Rolph has studied this question experi-

[1] *Trans. Illum. Eng. Soc. U.S.A.*, Nov. 1912.

mentally, and came to the conclusion that the direct component of the horizontal *illumination* should preferably not exceed 15 per cent. By blocking out different zones of the ceiling with dark cloth he has also sought to ascertain the best distribution of brightness thereon, and the ideal form of polar curve, which we have reproduced in fig. 135. This was obtained in a room $20\frac{1}{2}$ feet square and 10 feet high, the distance of the rim of the inverted bowl from the ceiling being 3 feet. The coefficient of reflection of the ceiling was approximately 74 per cent. It will be observed that the shape of curve is practically equivalent to

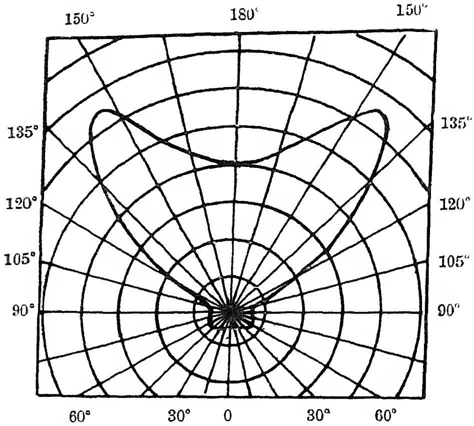


FIG. 135.—Ideal form of curve for semi-indirect lighting, designed with a view to producing the percentage of direct light most satisfactory for shadows (Rolph).

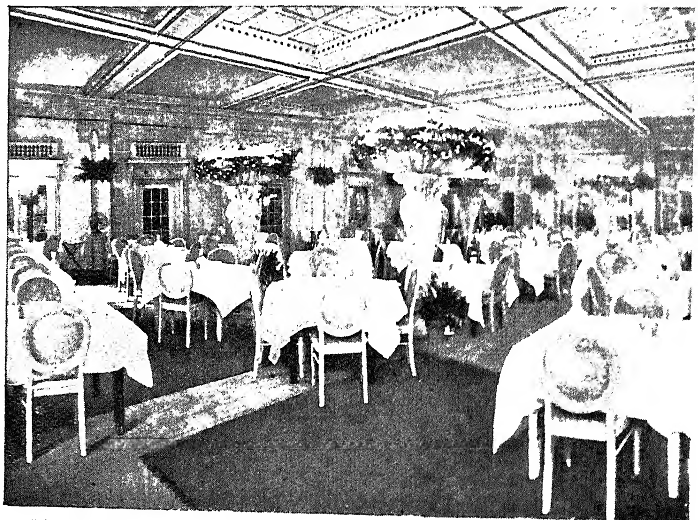


FIG. 136.—A view of an American restaurant lighted by X-ray pedestal units.

indirect lighting, the direct component being only about 6 per cent. of the total flux of light from the source. The author

apparently takes the view that the direct component is chiefly valuable in order to provide a visible source, and for decorative effect. These conclusions are interesting, but in view of the variation of interiors, and the widely different purposes for which semi-indirect lighting is used, it would probably be best not to attempt any very rigid prescription at present.

There is one novel method of direct and semi-indirect lighting, which seems to have interesting decorative possibilities, which has recently been developed—namely, "pedestal lighting." A room may be illuminated by translucent reflectors mounted on pedestals or columns and throwing most of their light on the ceiling. Fig. 136 shows the dining-room in an American hotel lighted in this way. The lamps are concealed in "X-ray" reflectors, mounted in white pedestals well above the eye level, and the effect is said to be very pleasing.

Miscellaneous Lighting Appliances and Fixtures.

In conclusion a few words may be said on shades and reflectors for special purposes. The types of reflectors described previously were designed mainly for "general lighting." But there are many instances in which it is desirable to concentrate the light in a special way and to light up only a limited area.

One of the most familiar examples is the stage, where the footlights concentrate the light on the actors but conceal the sources completely from the audience. Similarly, in lighting a shop window, trough reflectors, containing a row of electric incandescent lights, may be mounted above the window, concentrating the light on the goods below but screening the lamps completely from the eyes of the prospective customer. The best shape for such reflectors varies according to the height and depth of the window. Occasionally they may be hung in full sight of the people on the pavement, and are then usually made of some appropriate translucent material, and may be used to carry a name or trade-mark, or to convey some information to the prospective consumer. In fig. 137 we give an illustration of a novel gas-lighting fitting, containing a row of inverted mantles, flanked with plates of mirrored glass. This has a strong concentrating effect.

Sometimes it is desired to direct the light over a still smaller area. This occurs in connection with fine engraving, jewellery, and microscopic work, and it is usual in these cases to fall back

on a lens system and, if possible, to use a source of small area. There are also many industrial operations in which small cutting tools and needles require a strong local illumination at the point of contact with the material. Fig. 138 shows an ingenious system so used in connection with sewing-machines, the source consisting of a small tungsten lamp fed from a battery of accumulators. The essential idea in such cases is to get the light away from the eye and bring it close to the work. Jewellers sometimes use a bottle of green-coloured water with a lamp behind for the same purpose. For etching and lithography work, on the other hand, where the operator works mainly by the aid of the reflected light on a more or less polished surface, a source of light spread out over a large area (*e.g.* a lamp placed behind a sheet of semi-translucent paper) may be preferred.

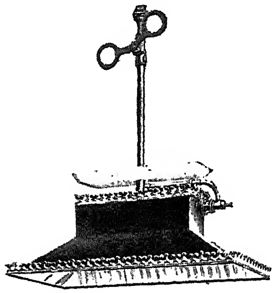


FIG. 137.—Sugg window reflecting light, containing a series of inverted mantles inside a rectangular mirrored reflector, and furnishing a strong downward illumination, suitable for shop-windows.

The devices used for concentrating light in the optical lantern, the searchlight, and the cinematograph form a very specialised section and constitute lens and systems rather than reflectors. The chief need here is for a very small concentrated source. It is possible that the advances in making tungsten lamps with very compact filaments may lead to developments in this class of work. There are also many problems in industrial lighting where the use of such filaments with appropriate reflectors would give a welcome gain in concentration.

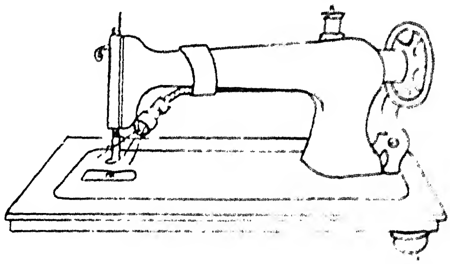


FIG. 138.—Arrangement of small 4-volt electric glow-lamp for the local lighting of sewing-machines.

The source is so near to the point of work that a very intense illumination results (9 to 27 foot-candles). The system has the great advantage of casting the shadow of the needle-holder in the right direction. (See Report of H.M. Chief Inspector of Factories, 1911.)

There is room for careful design in connection with portable lamps, standards for reading-desks, desk lights, etc. The essential points to be observed in such cases are that the lights

should be completely screened from the eyes of the reader, and the illumination over the desk should be as uniform as possible. It is a common defect for the illumination to be unequally distributed—too bright in some places and insufficient in others. Such inequalities can be avoided by correct design.

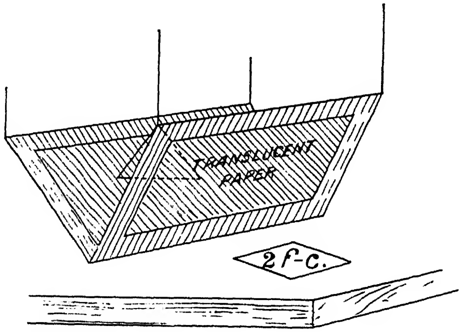


FIG. 139.—Device used for etching and lithography at the Arts and Crafts School. The light is placed within sheets of translucent diffusing paper.

Besides distributing the light uniformly, reflectors used with portable lamps should be arranged so as to avoid "striations," which are particularly trying to the eyes in close work. Theoretically quite small units, such as 8-c.p. lamps, should be sufficient to give a high uniform illumination over a considerable desk area. With an appropriately designed unit the use of frosted or slightly opalescent surfaces is quite permissible, and is an effectual means of overcoming striations.

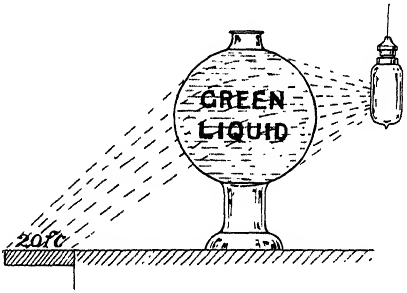


FIG. 140.—Globe of green liquid sometimes used by jewellers and engravers to focus the light on the spot where work is done.

One not infrequently meets with cases where the shade is brought down close to the desk, giving an illumination of 50 or even 100 foot-candles, a value which is surely excessive for ordinary reading and writing. It is sometimes advocated that stand lamps in libraries should be adjustable, so that readers can arrange the intensity of the light to suit their convenience, but it may be questioned whether this is necessary if a reasonable illumination of 3 to 5 foot-candles is provided. There are special classes of work, such as tracing fine diagrams in drawing-offices, where a considerably higher illumination is doubtless needed; for such work a highly concentrated opaque reflector may be used and should preferably be adjustable. This enables the draughtsman to work with an illumination of about 5 foot-candles for large

work, but to increase this value when he has to deal with fine details.

There is also a demand for fixtures intended to illuminate large vertical surfaces, such as pictures, bill-boards, etc. By using suitably spaced parabolic reflectors, at a moderate distance from the surface, a powerful and fairly uniform illumination can be obtained. Appliances of this kind are very usual for the external lighting of shop windows, and they are also coming into use for illuminating advertisement hoardings, maps and signs outside railway stations, etc. In some cases the back of the reflector can be made of some translucent material such as thick opal glass, forming a luminous screen on which the name of a shop or any other information can be inscribed. Flame arcs and high-pressure gas lamps are now frequently provided with these reflectors, and in these circumstances the conditions of illumination are more satisfactory than when the full blaze of the lamps is allowed to stream into the streets.

When the reflector can be placed at a moderate distance from the surface to be illuminated, this type of unit does its work very well. For certain classes of work, *e.g.* lighting placards in school-rooms, some authorities consider it desirable that the source should not be too near. Otherwise the rays, striking the surface so obliquely, are apt to illuminate small particles of chalk and dust, giving rise to a species of "luminous haze." This would interfere with the distinctness of the diagrams and figures marked on the board.

On the other hand, there are certain cases—for example, the lighting of pictures—in which the arrangement is apt to appear clumsy if the source projects to any great extent. As an instance of line reflectors designed to give uniform illumination, we may mention the Holophane Uniflux reflector, described before the Illuminating Engineering Society by Mr V. H. Mackinney in 1911. This consists of an opaque mirrored glass reflector, with a contour specially designed to give uniform illumination over a vertical surface. It is conveniently used with tubular sources of light. The course of the rays will be understood from fig. 141c. Provided the distance of the source from the surface is correct, the illumination is said to be very uniform, practically all the light being concentrated over the area to be lighted. Under these circumstances it only requires quite a small flux of light to illuminate a large area. A length of any prescribed number of feet of this reflector is used, according

to the width of the area to be lighted. The expenditure in electrical energy and in lighting such a surface would be about 0·5 watt per lumen with ordinary electric metal-filament lamps. For example, to light up an area of 100 square feet with an illumination of 5 foot-candles should not need more than about 250 watts. This reflector is specially adapted for picture lighting. The source of light is completely concealed from the eye, and the

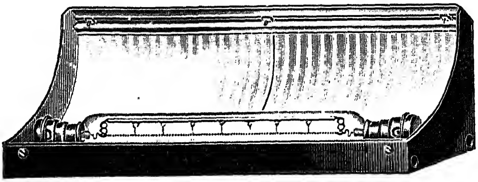


FIG. 141A.—Holophane Uniflux reflector for shop lighting.

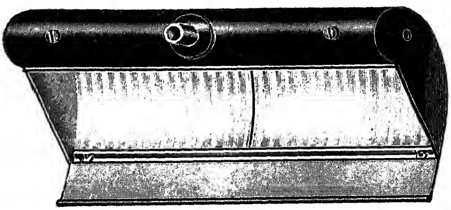


FIG. 141B.—Holophane Uniflux reflector for hoarding lighting.

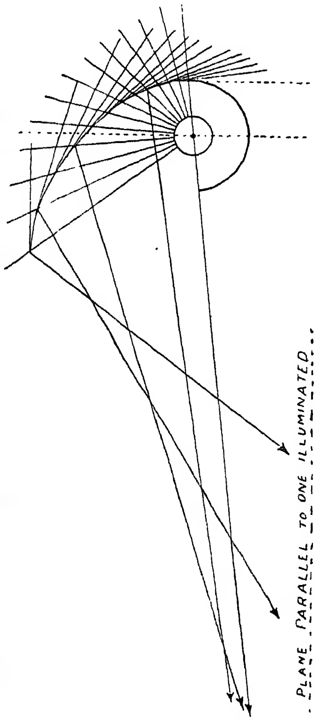


FIG. 141C.—Showing course of rays of light reflected from the Uniflux surface.

distance of a source from the surface is so selected that the observer, when looking towards the illuminated area in the ordinary way, does not see any troublesome images of the source in the glass.

A great deal might be said on the design of purely ornamental types of shades and fixtures. There are often cases in which the idea of high efficiency has to be subordinated to the production of something tasteful and decorative. An instance in point is afforded by the development of illuminating

engineering in Japan, where the people have been used f
years to the soft and mellow light of lanterns, and are
prefer the soft hues of illuminated silk and paper ratl
the sparkle from metal and glass. It seems highly
that in that country, where the decorations of silk ar
are a traditional art, illuminating engineering will pr
somewhat different lines from those in Europe. As an
of such special design we may take fig. 142, which il
some decorative fixtures, the design being adapted f
Chinese. Fig. 143 shows one of the central chand

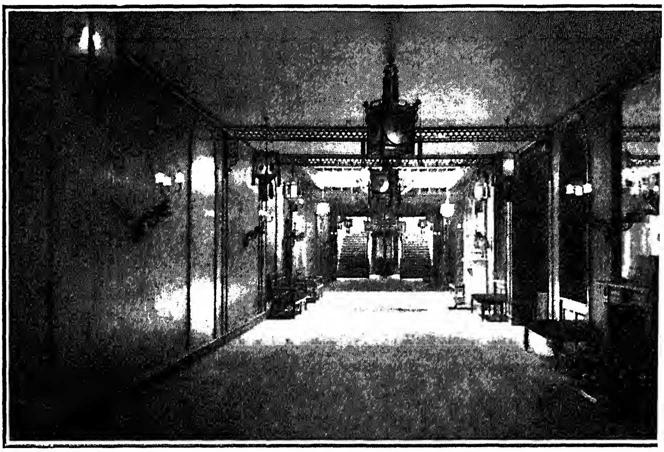


FIG. 142.—Corridor in the Royal Pavilion, Brighton, illumina
by lamps in silk-shaded oriental lanterns.

a banqueting-room, where the shades are made of
glass in imitation of Chinese lilies. An interesting
the dragon at the top of the chandelier. In the
ornamental lanterns are used and the effect is decid
and pleasing.

Quite simple devices are sometimes used with excel
For example, in one of the best known theatres in
lighting on the landings is carried out by a light pla
a sheet of light canvas stretched on a frame and a
such a manner as to screen the eyes of people comi
stairs, but to transmit sufficient light on the carp
Another contrivance that has occasionally been used i
is the provision of lamps in little niches in the wall,
covered by decorative diffusing glass. Some novel de

recently described by Dr H. E. Ives.[1] Among these are the use of large paper surfaces (not unlike inverted Japanese umbrellas) under a central fitting. Ives has also experimented with curved wall reflectors having a matt surface, which, when illuminated, returns the light into the room in somewhat the same way as daylight is received from the average window.

Finally, a few words may be said on the general design of fixtures, which has frequently to be worked out conjointly with the globes and shades. Here, again, there are often cases where the illuminating engineer should not insist too strongly on high efficiency. An antique chandelier may often be preferred and retained on account of its associations, in spite of the fact that it is inconvenient and a very imperfect device for the distribution of illumination. Many of the old cut-glass chandeliers used in large rooms decorated in the French style are open to criticism from a utilitarian standpoint, and, in themselves, might even be considered inartistic. Nevertheless they may be essential to the general scheme of the interior in order to carry out the general style and period to which it belongs. As an instance, we recall the very large chandeliers used in some of the rooms in the palace of Versailles. Moreover, it must be remembered that such fixtures are often valued for their appearance by daylight; cut-glass appears at its best under these conditions. If the lighting expert is to take a share in the illumination of old interiors of this kind, he should understand thoroughly the architectural style and study how the architectural and artistic aspects of the problem can best be reconciled. The imitation antique lanterns and statuettes found in modern catalogues afford an opportunity for practical skill in

FIG. 143.—Chandelier in the Chinese style (banqueting-room at Royal Pavilion, Brighton).

[1] *Trans. Illum. Eng. Soc. U.S.A.*, June 1913.

wiring as well as taste. We have met with cases in which the designer was apparently out of touch with wiring matters, and allotted so little space that it was hardly possible to draw in the wires without spoiling the insulation; on pressures of 220 to 240 volts, which are not unusual in England, a short circuit, with a possible danger of fire, might be caused in this way.

The question of the introduction of modern illuminants in old mansions and in buildings of architectural historic importance is a difficult one. One frequently meets instances where the old illuminant is stubbornly retained and gas and electric lighting are denied entrance, and one can understand the feeling which leads to such a decision. On the other hand, there are cases in which highly modern and tawdry fittings and inferior workmanship are responsible for incongruity, the architect having apparently resigned himself to the innovation but abandoned all hope of carrying it through in an artistic manner. The claims of modern comfort are making themselves felt, and every year the number of these old buildings clinging to the old illuminants becomes less. In many cases the change can be made without any incongruity being evident, and the skill of the lighting expert should be applied to reconcile the claims of practical convenience and artistic effect.

In speaking of fixture design the mind naturally turns first to interior lighting. Yet it may safely be said that the opportunities for creative skill in connection with outdoor illumination are quite as great. We shall return to this matter in Chapter X. Meantime, it may be said that the charm of a city by night is in a great measure dependent on the way it is lighted. It cannot be denied that the design of many existing lamp-posts and wall fittings might be improved.

Both indoors and outdoors there is ample opportunity for the lighting engineer gifted with the artistic sense.

CHAPTER IX.

PROBLEMS IN INTERIOR ILLUMINATION.

General Recommendations on Illumination—Consumption of Gas, Electricity, etc., to produce a given Illumination, with direct, indirect, and semi-indirect systems—Effect of Reflection from Walls and Surroundings on such Calculations—Intensity of Illumination required for various purposes—"General" and "Special" Illumination—Shadow-effects and the Direction of Light—Local and General Methods of Illumination—Comparison of Natural and Artificial Light—Domestic Lighting: Illumination of Halls, Drawing-room, Dining-room, Bedrooms, etc.—Lighting of Clubs, Hotels, and Restaurants—Lighting of Banks, Offices, etc.—School Lighting, daylight problems and artificial illumination—Library Lighting, requirements of various classes of libraries—Recommendations of Committee of the Illuminating Engineering Society on above subjects—Industrial Lighting, the value of good illumination as a hygienic and economic necessity and as a means of preventing accidents—Conditions of Illumination required in various types of Factories—Lighting of Halls, Concert Rooms, Theatres—Hospital Lighting, illumination of wards and operating tables—Problems in Church Lighting, the reconciliation of æsthetic and practical aspects in various places of worship—Illumination of Picture Galleries and Museums—Shop Lighting, distinction between Advertisement Lighting and Illumination of Contents of Show-windows—Lighting Conditions inside the Shop, and requirements of large Stores—Lighting Installations for Games played under cover—Illumination of Gymnasiums, Lawn-tennis Courts, Squash-racquet Courts, etc.—Decorative and Spectacular Lighting and the Production of Scenic Effects.

WHEN we come to consider general problems of illumination we find that success is dependent mainly on two factors—the correct positions of lights and effective shading. Much that has been said in the last chapter might equally well have been included here. Anyone who understood the design and use of globes, shades, and reflectors should be able to form a fairly definite idea of the main essentials of good lighting.

In this chapter we propose to discuss a number of miscellaneous problems, which will illustrate the value of the suggestions made in the last chapter. But before doing so there are one or two points that deserve a little elaboration.

At this stage we cannot do better than repeat some simple rules of good lighting preserved in a recent publication issued under the auspices of the Illuminating Engineering Society.[1]

[1] *Light and Illumination: their Use and Misuse*, reprinted from the *Illuminating Engineer*, London, Dec. 1912.

SOME SIMPLE RULES OF GOOD LIGHTING.

Don't work in a flickering light.

An unsteady, flickering illumination is extremely trying to the eyes.

Don't expose the eyes to unshaded lights in the direct range of vision.

Glare from brilliant unscreened sources of light is prejudicial to eyesight, and prevents you from getting the best results from the illumination provided. Lamps should preferably be placed fairly high up in a room out of the direct range of light. If local lights, low down and near to the eyes of the worker, are used, they should be covered by a suitable opaque shade. Do not read facing the light.

Don't judge illumination by the brightness of the lamps.

Do not think because a lamp looks glaring and brilliant that it is giving you a good light. It may be merely giving too much light in the wrong place. On the other hand, a well-shaded lamp may look dim *because* it is well shaded, and may still be giving a first-class light to work by.

Avoid excessive contrasts.

If you use a table lamp to provide a strong local illumination, do not leave the rest of the room in complete darkness. Provide a moderate general illumination.

Use the right type of globe, shade, or reflector.

Some forms of globes and reflectors are intended to diffuse the light evenly in all directions; others concentrate the light mainly in one particular direction. See that you get the kind of shade which the local conditions demand. Avoid very shallow reflectors, such as only cover part of the lamp.

Make sure that the illumination is sufficient.

Proper illumination should be provided on the spot where work is actually carried on. 2 to 3 foot-candles is usually enough to read by. More is needed for special fine work, and when the materials to be illuminated are dark in colour and reflect little light. Rooms with dark walls and ceiling require a greater illumination than those in which the surroundings are light in tint.

Keep lamps, globes, and reflectors clean.

Accumulations of dirt on lamps, chimneys, globes, etc., absorb and waste a great deal of light.

Make sure that lamps are in the right position.

When selecting the positions for sources of light, consider carefully what purpose they are to serve, and remember the motto, "Light on the object, not in the eye." See that the light comes from the best direction, and that it does not give rise to inconvenient shadows.

Consumption of Gas or Electricity to produce a Certain Illumination.

In comparing methods of lighting it is necessary to state not only the consumption of gas, electricity, etc., but also the amount of illumination provided. In a very large number of practical cases we wish to distribute the light evenly all over the room, and it is then possible to specify the consumption of electricity "per lumen on the working plane" (*i.e.* per foot-candle per square foot of area illuminated).

When the light is less evenly distributed one can often form a fair idea of the *average* illumination over the area to be lighted.

On this basis we may summarise the results given in previous chapters as follows:—

Specific Consumption for Various Systems of Lighting.[1]

Illuminant.	System of Lighting.	Specific consumption per lumen on the working plane (*i.e.* per foot-candle per sq. foot illuminated).
Gas	*Direct* (low pressure)	0·01 –0·02 cu. ft. per hr. per lumen.
	Direct (high pressure)	0·003–0·01 „ „
	Indirect (low pressure)	0·02 –0·04 „ „
	Indirect (high pressure)	0·005–0·02 „ „
Electricity	*Direct*—	
	Tungsten lamps	0·2 –0·3 watt per lumen.
	White carbon arc	0·1 –0·2 „
	Flame arc	0·05–0·1 „
	Semi-indirect—	
	Tungsten lamps	0·3 –0·4 „
	Arc lamps (white light).	0·15–0·2 „
	Indirect—	
	Tungsten lamps	0·4 –0·6 „
	Arc lamps (white light).	0·2 –0·25 „
	Moore tube	0·4 –0·8 „
Acetylene	Average direct lighting	0·01–0·02 cu. ft. per hr. per lumen.
Petrol-air gas	Average direct lighting	A consumption of 1 gallon of petrol per hour would give 10,000–20,000 lumens.

[1] A similar but somewhat more elaborate table is given in Uppenborn's *Lehrbuch der Photometrie*, p. 179.

We give these rules as a very rough basis on which to form an idea of the consumption necessary to give a convenient illumination in a room of specified size. Much naturally depends on the type of reflectors used, and the proportion of light allotted to the walls and ceiling in comparison with the "working plane." The figures given above are based mainly on data obtained from a number of up-to-date installations, and it is assumed that good modern types of fixtures, suitable for the purpose in view, are employed. In one respect this system of comparison is not quite fair to indirect and semi-indirect systems, since it leaves out of account the larger amount of illumination given to the walls and ceiling. In interiors where vertical surfaces are used, such as pictures, bookcases, etc., requiring extra light, this should be borne in mind. The same remark applies to the Moore tube system, which naturally emits much more light in the upper part of a room than a series of lamps in reflectors would do.

One finds that the conditions of illumination have already become partially standardised in the case of the more systematic methods of lighting. For example, in an average installation of tungsten lamps with good translucent reflectors, a consumption of 0·5 watt per square foot and an illumination on the working plane of 2 foot-candles is very usual. On the other hand, the illumination in rooms lighted with inverted gas mantles is usually somewhat higher, perhaps 3 to 5 foot-candles. Most rooms lighted with inverted arcs, again, receive about 0·8 to 1 watt per square foot and an illumination of 4 to 6 foot-candles. In acetylene and petrol-air gas lighting for country houses, etc., 1 to 2 foot-candles is more usual. In these cases the illumination provided is to some extent a consequence of the size of the units available.

Effect of Walls and Surroundings.

It is comparatively easy, as we have seen in the previous chapter, to arrange the spacing and height of units so as to get an even illumination of a certain intensity, and when a moderate general illumination, supplemented by strong local lighting, is demanded, we can readily calculate from the polar curve what the illumination immediately under a unit hung at a certain height will be.

In the published data relating to various systems of lighting the effect of reflection from walls and surroundings is usually left out of account, and it may be necessary to multiply the results by a suitable factor.

The effect of reflected light from surroundings was investigated by Dr Sumpner nearly twenty years ago. It is discussed by Dr Louis Bell[1] as follows:—

If the radiant in a closed space furnishes a certain quality of light, L, then the strength of the illumination produced at any point within the space will depend, if the walls are non-reflecting, simply on the amount of light received from the radiant, in accordance with the law of inverse squares. If the walls reflect, then the total illumination at any point will be that received directly, L; and in addition a certain amount, kL (where k is the coefficient of reflection), once reflected; a further amount, k^2L, twice reflected, and so forth. The total illuminative effect will then be—

$$L(1+k+k^2+k^3 \ . \ . \ . \ k^n).$$

As k is obviously always less than unity, this series is convergent upon the limiting value $L/1-k$, which expresses the relative effect of the walls in reinforcing the light directly received from the radiant.

A good idea of the practical amount of help received from diffusion may be gained by computing the effect for various values of k. The following table shows the results for values of k between 0·05 and 0·95:—

k.	$\frac{1}{1-k}$.
0·95	20·00
·90	10·00
·85	6·66
·80	5·00
·75	4·00
·70	3·33
·65	2·85
·60	2·50
·55	2·22
·50	2·00
·45	1·81
·40	1·66
·35	1·53
·30	1·42
·25	1·33
·20	1·25
·15	1·17
·10	1·11
·05	1 05

In practice the operation of reflection is, of course, much more complicated, for the walls, ceilings, dados, and furniture all differ in reflecting power, and their effect would have to be separately considered. It is also to be expected that the effect of surroundings will depend to a considerable extent on the size of the room. Moreover, the effect will obviously vary according

[1] *The Art of Illumination.*

to how much of the light strikes the walls and ceilings. If an interior is lighted entirely by lamps in opaque reflectors hung at a low level, the upper parts of the room are in complete shadow, and the nature of the ceiling is of small consequence; on the other hand, in an indirect installation, where the light is thrown straight upwards on the ceiling, its reflecting power is a very vital matter indeed.

Even in the case of direct lighting with translucent reflectors the results will naturally differ according as scattering or concentrating glassware is used. A table presented by Mr V. H. Mackinney at a meeting of the Illuminating Engineering Society [1] contains some results obtained in a small room with various Holophane reflectors.

The following table has been used by some firms interested in illuminating engineering, and is a rough guide to the probable increase in illumination :—

Condition of Ceiling.	Condition of Walls.	Increase over Calculated Illumination.
Very dark.	Very dark.	0 per cent.
Medium.	,,	15 ,,
,,	Medium.	40 ,,
Very light.	Very dark.	30 ,,
,,	Medium.	55 ,,
,,	Very light.	80 ,,

This table, however, takes no account of one very important factor—the size of the room. In very large halls the reflecting surfaces are distant and add little to the illumination; in a small room reflection from surroundings may have a very marked effect.

Evidently the system of decoration used is an important factor. It is often singularly difficult, even by using a very powerful illumination, to produce a satisfactory effect in a room having very dark walls, which reflect little light. The fact of the surroundings being so subdued gives the impression that the room is underlighted, and the lack of proper diffusion has inconvenient practical consequences. In a room with light walls rays are reflected from all directions, and the room gives an impression of being "filled with light," as it is in the daytime. These rays strike solid objects from all quarters, illuminating

[1] *Illum. Eng.*, London, vol. iv., 1911, p. 362.

them completely and giving a proper perspective and "body," which satisfies the eye. The shadows also are softened. But when the surroundings are dark we have to depend entirely on direct reflection, and an object is rarely completely lighted as it would be in daylight. Deep and harsh shadows are thrown by objects and projections in the room, and in many instances they are decidedly inconvenient.

There are, of course, instances in which the illuminating engineer is asked to light old interiors panelled in dark oak or surrounded by sombre tapestry, and must do the best he can. In such cases it is preferable, when the dimensions of the room permit, to use large sources in which the light is spread over a considerable area, so as to soften the shadows and, to some extent, make good the lack of reflecting power. But in new buildings, and in schools, offices, and factories, etc., where the scheme of decoration and colour of the walls and ceiling are optional, light tints are certainly preferable.

Intensity of Illumination required for Various Purposes.

The most approved method of specifying the amount of light needed for any operation is to state the actual illumination on the spot where the work is carried out. For example, we find a general recognition that for ordinary reading and writing the illumination on the desk or table should not be less than 2 to 3 foot-candles. The intensity of the illumination in other parts of the room is usually less important, although naturally one would provide enough light to enable objects to be clearly distinguished, and to avoid unduly severe contrast between the subdued surroundings and the brightly illuminated desk.

Rules based on the provision of a certain candle-power per square foot of floor area, or per cubic foot of space in the room to be lighted, are still sometimes quoted. But this is only a very rough guide, since nothing is said as to the distribution of the light, nor the effect of the reflectors used with the lamps. It is quite possible, if the shading of the sources is not properly studied, that a large number of lamps of high candle-power may be used and yet a very poor illumination obtained at the spot where it is needed.

The amount of illumination required naturally depends mainly on the purpose to which a room is to be put. In general all one attempts to do is to state the *minimum* desirable. A

distinction may at once be drawn between the "general illumination" and the "special illumination" required for particular purposes. A certain minimum general illumination is required in order to enable people to see their way about, to distinguish relatively large objects, and to do simple work, such as does not impose any considerable tax on the eyes. An illumination of this order should be provided in yards, corridors, railway platforms, and in parts of the room where no detailed work is carried out and people merely pass to and fro.

There seems to be a general recognition that the value in such cases should not be less than about 0·25 to 0·5 foot-candle, and 1 foot-candle would certainly be ample. (This illumination is usually specified to be measured in a horizontal plane 1 metre from the floor.)

In considering the *special illumination* required for specific purposes we find endless variety. In comparatively few cases has the amount of illumination that is strictly necessary been accurately determined. If one visits a number of workshops of the same class, one finds absolutely identical operations being carried on with widely different intensities of light; and only in a few instances is there yet any evidence of standardisation.

As stated above, there is fair agreement that 2 to 3 foot-candles is sufficient for ordinary reading and writing. It was explained in Chapter V. that the human eye becomes more or less saturated at this point, and any further increase in illumination does not lead to a great improvement in visual acuity.

For the study of very fine print and the tortuous and intricate lettering of oriental languages, and for reading music and shorthand, a somewhat higher value would usually be considered necessary, and also for reading distant notices, placards, figures on a blackboard, etc. Again, in drawing-offices, where the tracing of fine lines is done, 5 or even 10 foot-candles would probably not be excessive.

When we pass on to more minute work we find a demand for a higher illumination still. Watchmakers and engravers not infrequently use a concentrating reflector or lens giving 20, 30, or even 50 foot-candles.

Finally, it must be remembered that there are many cases—show-window lighting, spectacular and advertisement illumination, etc.—where the light is provided for the sake of a display,

and the amount that is strictly necessary for the purpose of merely enabling things to be seen can profitably be exceeded.

In applying these data we must not lose sight of the fact that the item with which we are most intimately concerned is

TABLE VII.—MAXIMUM FOOT-CANDLE INTENSITIES RECOMMENDED FOR VARIOUS CLASSES OF SERVICE.

Art gallery (walls)	5·0
Automobile showroom	6·0
Bank (general)	2·0
Bath (public):	
Dressing-rooms	1·0
Swimming-bath	2·0
Billiard room (general)	1·0
,, table	15·0
Courts:	
Squash	6·0
Tennis	6·0
Church	3·0
Desk	4·0
Drawing-office	8·0
Drill hall	3·0
Engraving	10·0
Factory:	
General illumination only where additional special illumination of each machine or bench is provided	1·5
Local bench illumination	4·0
Complete (no local illumination)	4·0
Garage	2·0
Gymnasium	2·5
Hospital:	
Corridors	0·5
Wards (with no local illumination supplied)	1·5
Wards (with local illumination supplied)	·5
Operating table	12·0
Laundry	1·0
Ironing table	4·0
Library:	
Stock room	1·5
Reading-room (with no local illumination)	4·0
Reading-room (with local illumination)	1·0
Market	3·0
Moving-picture theatre	2·0
Museum	3·0
Office (general)	4·0
Power house	2·0
Railway carriage	2·0
Reading (ordinary print)	4·0
,, (fine print)	6·0
Residence:	
Porch	0·5
Hall (entrance)	1·0
Drawing-room	1·5
Sitting-room	1·5
Dining-room (general)	0·5
(Local on table)	4·0
Kitchen	2·0
Bedroom (general)	1·0
Dressing-table	4·0
Restaurant	3·0
Rink (skating)	3·0
School:	
Class-room	3·0
Corridor	0·5
Sewing	6·0
Shop window:	
Light goods	8·0
Medium goods	16·0
Dark goods	20·0
Shops (interior):	
Light goods	5·0
Dark goods	10·0
Station (railway)	2·0
Street:	
Business (not including light from shop windows, etc.)	0·5
Residence	0·1
Country roads	0·05
Studio	4·0
Theatre:	
Lobby	3·0
Auditorium	2·0
Train shed	1·0
Type-setting	8·0
Warehouse	1 5
Wharf	1·0

The minimum values used should not be less than half the maximum values stated above.

the actual amount of light entering the eye. For example, a person reading an age-stained parchment would require much more light than if he were examining type on a clean white page. For when such parchment receives the specified reading illumination it reflects but little light freely upon it, and its actual brightness is really very much less than that of a good white surface.

Again, in trades involving work on dark materials an abnormally high illumination is needed. A person doing needlework on dark clothing, having a reflecting power of only 5 to 10 per cent., might require as much as 50 foot-candles.

The state of adaptation of the eye should also be considered. The above figures apply to normal conditions. A person who has spent a long time in a dark room and whose eye has become adapted to the feeble light, can see by a surprisingly weak illumination, and on entering a moderately lighted room finds it at first quite distressing. Similarly, a person who has been spending some time in a blaze of light finds an ordinary illumination insufficient.

Tables on this subject have frequently been prepared by firms interested in illumination. In Table VII. above we give a typical collection of values, taken from the *Holophane Engineering Data Book*. But it must be remembered that these figures are based on experience of present-day conditions, and that in many cases confirmatory investigations are needed. In other words, they summarise existing practice but do not necessarily represent the ideal conditions.

Shadows and Direction of Light.

After what has been said in Chapters V. and VII., and again summarised in the extract from *Light and Illumination: their Use and Misuse* (quoted above), it seems hardly necessary to repeat the caution as to the avoidance of glare. Some specific examples of its inconvenience in practice will be mentioned shortly.

The closely allied questions of the effects of *shadow* and the direction from which light is received were also touched on in Chapter VII. It was remarked that one important function of a globe is to remove harsh and abrupt contrasts of light and shade. There seems to be a lack of some standard method of specifying conditions of shadow, and very

little has yet been done on this subject. A few observers have demonstrated the value of photometric tests of surface brightness in attacking such problems. Eck has employed such measurements in order to compare the gradation of tone on a statue illuminated successively by natural and artificial light.[1]

Clark and Mackinney have constructed a "shadow-tester," consisting of a small sphere and disc of specified dimensions at the end of a rod,[2] and the subject was again referred to in a paper by Dow and Mackinney in 1913.[3]

K. Norden has evolved a method of expressing shadows numerically, and defines the diffusion of a source in terms of the ratio between the brightness of the shadow area and the surrounding fully illuminated region. The diffusion would be uniform (and perfect) when there is absolutely no shadow. A "point-source" amidst dead black surroundings would give shadows of maximum density, and its diffusion would be zero. The "shadow-power" would then be $1-D$, when D denotes the diffusion. Most systems of artificial lighting would have a value for D intermediate between unity and zero.[4]

Some writers have used the term "diffusion" to indicate the uniformity of brightness of the radiating area of a source, or of the shade surrounding it. A distinction is necessary between this quantity and the "illumination diffusion" as regards shadow produced by an artificial lighting system. This "illumination diffusion" would depend on many distinct factors, chief among which are the method of shading and the nature of the surroundings.

But the nature of a shadow is not completely specified by merely stating its darkness in comparison with that of a surface receiving full illumination. Besides the depth of a shadow, the manner in which it fades away at the edges is often important. A shadow may be light in tint, but nevertheless may have very dark edges; and a shadow that is extremely dense in parts often fades away very smoothly. For this reason a good photograph is perhaps one of the best methods of representing conditions of light and shade; but the exposure and development must be carefully judged in order to reproduce the gradation in tone accurately.

[1] *Electrician*, May 26, 1911.

[2] *Illum. Eng.*, London, March 1913.

[3] *Ibid.*, Dec. 1913.

[4] *Elektrot. Zeitschr.*, 1911, p. 607.

The influence of shade is more important in practice than is generally supposed. Shadows cast by the head in reading, or by the hand when writing or drawing, may be exceedingly inconvenient. A strong light immediately overhead is a constant source of trouble to a person whose occupation involves bending over a desk and who finds himself continually "in his own shadow." This is illustrated in fig. 144, which is taken from the paper by Dow and Mackinney referred to above. Low-hung, imperfectly shaded chandeliers have the same effect. One cannot find a position in which the pages of a book are neither underlighted nor overshadowed. Multiple shadows cast by a series of unscreened sources and flickering shadows cast by moving machinery are particularly trying. Multiple shadows make it difficult to follow the course of any rapidly moving object, and therefore should be avoided in a scheme of illumination devised for any ball game, such as lawn-tennis, racquets, etc.

FIG. 144.—Showing inconvenient head shadow from overhead light.

The question of the best direction of light is largely a matter of shadow. Light coming from the left hand of a person writing gives little trouble, because the shadow of his right hand does not fall upon the words being written. But a strong light from the right hand is decidedly troublesome. For this reason modern school-rooms are always lighted from windows on the left. In the same way the sound rule "not to read facing the light" is justified by the fact that one's book is usually in partial shadow in these circumstances.

In any room containing many projections and recesses, cupboards, racks, pigeon-holes, etc., unduly dense shadows have to be guarded against. If a system of pure direct lighting with opaque shades is used, inconvenient shadows are apt to be cast by cupboard doors, etc., and the light may fail to penetrate properly into the interior of open drawers or pigeon-holes.

The same applies to rooms in which it is necessary to look underneath complicated machinery, as in printing and motor-car works.

In all such cases much can be done by effective methods of shading, which spread the light from the source over a larger area and soften the shadows; and by the use of light walls and ceilings, which, by diffusely reflecting the light in all directions, add considerably to its effective value. The use of a number of well distributed small units in preference to a few powerful ones is also advisable.

But in cases where shadows are apt to be particularly troublesome, the judicious use of indirect and semi-indirect lighting is even more advantageous. This point was referred to in the last chapter. When the entire area of the ceiling becomes the source of light, there will be few points in the room which are not reached by a large proportion of the reflected rays: and since the light comes from so many different directions the shadows are very slight.

FIG. 145.—Shadow cast by light on the *right*; falling on writing and interfering with the view of the letters.

FIG. 145A.—Shadow cast by light on the *left*; does not fall on letters and causes no trouble.

Another advantage of indirect and semi-indirect systems is that the inclination of the surface to be illuminated is not so vital. In a room lighted entirely by direct means the effect of tilting one's book may be to diminish the illumination on the page considerably. But when the light comes from a large area this effect of tilting is usually much less pronounced.

It has been stated that, in order to see an object properly, it should in general be illuminated by rays of light coming from many different directions; and that light-tinted surroundings, which diffuse the light, are therefore very beneficial. On the other hand, a certain amount of "contrast" or "relief" is always needful in order to give solidity to an object, and enable the eye to appreciate that it is "three-dimensional." An entirely shadowless illumination (which is, fortunately, a very difficult thing to obtain in practice) would be of very little service.

There are even cases in which light coming from one direction only is needed. It is common knowledge that light striking the page of a book very obliquely is of little value for reading purposes, because it shows up all the small imperfections or uneven gloss of the paper. But for this very reason experts, when examining samples of paper, frequently tilt them so as to receive light at a very large angle of incidence. In printing works, also, the workman making the final adjustment of the pressure on the machine deliberately arranges for the light to strike the paper very obliquely, so that he can detect the slight irregularities caused by type showing through from the other side. For this purpose light striking the paper vertically would be of little value. The beam from a motorist's head-light has exactly the same functions in showing up irregularities in the surface of the road.

It is possible that for certain operations—for example, in judging the texture of samples of cloth, knitting and quilting, etc.—one would require a system of lighting giving fairly sharp shadows, such as would show up slight surface irregularities clearly. The conditions required here may be quite different from those suitable for a room containing large machinery. This illustrates the need of some standard method of defining the "illumination diffusion" required for various classes of work.

This need is again exemplified when we come to the æsthetic aspects of shadows. There seems to be some difference of opinion as to the kind of lighting most suited for an art room—for showing up plaster casts, statues, etc. In some cases indirect and semi-indirect systems are approved; in other cases experts prefer a chandelier equipped with a number of lamps in diffusing globes and separately controlled, so that the total light-giving area (and consequently the depth of shadow) can be varied considerably.

These matters were discussed in a recent illustrated paper by M. Luckiesh.[1] One thing appears certain—that a bust or statue cannot be effectually lighted if the rays come from one direction only, and overhead direct lighting is particularly unsuitable. This is well illustrated in fig. 146A. Unidirectional lighting may distort the appearance of a face completely, changing a benign and cheerful expression into one that is gloomy or even ferocious. On the other hand, if the light is too entirely diffused, the tendency may be to obliterate the expression and produce a somewhat "flat effect."

The part played by shadow in the artistic lighting of

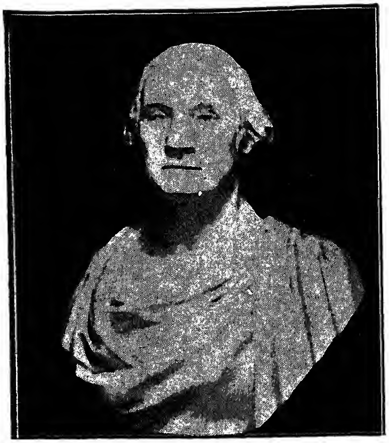


FIG. 146.—Bust lighted from above and in front.

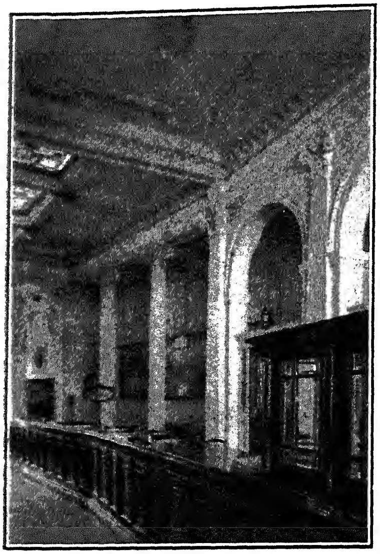
FIG. 146A.—The same bust lighted from directly overhead.

interiors has been very little explored as yet. Most interiors with any architectural pretensions have been designed with a view to their being seen by daylight. Where, instead of lighting from the side windows, we substitute a central chandelier or an illuminated ceiling, the appearance of pillars, recesses, alcoves, and carving generally may be quite different from what it is by daylight.

A curious effect, not infrequently met with, is the reversal of shadows by artificial light. For example, when lights are placed among pillars the latter stand out dark against a light background, whereas by daylight the contrary is probably the case; and in the same way the interior of an arch may be in shadow

[1] Read before the Am. Gas Institute, Oct. 1913; see also *Illum. Eng.*, London, vol. vi., Dec. 1913, p. 636.

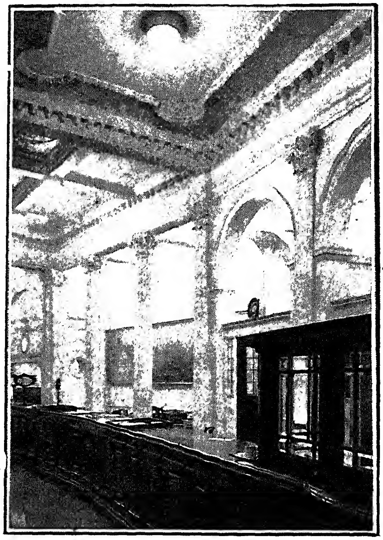
in the daytime, but a lantern hung within it may cause it to shine out amid its surroundings by night. It has been contended by some that the artistic possibilities of a fine interior should be even greater by night than by day, seeing that artificial light is so much more completely under control, and may therefore be used to accentuate features which do not receive this full value by natural light. This is a field in which



(Photo taken by daylight.)

FIG. 147.—A view of the office of the Allan Line (Cockspur Street, London, S.W.) by daylight.

The pillars stand out *light* against a dark background, and the interior of the arch is *lighter* than its surroundings.



(Photo taken entirely by artificial light.)

FIG. 147A.—The same view by artificial light.

Note the reversal of shadow. The pillars now appear *dark* against a light background, the inside of the arch is now *darker* than its front face instead of lighter, and even the grooves in the pillars appear as dark lines instead of light ones.

the help of the architect is needed, and on which very little has yet been said or done. A striking example of the contrast in appearance of an interior lighted respectively by natural and artificial means is shown in fig. 147.[1]

Many people would no doubt consider that the appearance of the room by artificial light is distinctly finer than in the daytime, and there seems no reason why, if an installation is carefully designed, this should not be the case.

[1] Dow and Mackinney, *loc. cit.*

Local and General Lighting.

The term "local lighting" is usually applied to cases in which each operator, or each section of a room. is treated separately and receives its own light; while "general lighting" implies that an even illumination is aimed at over the entire area, the light being equally requisite in all parts of that room.

In considering which of these two methods to employ, one should obviously be guided mainly by the purpose which the room is to serve. In lighting halls, meeting rooms, etc., where each person is treated alike and requires the same amount of light, a moderate general illumination would be needed. The same applies to rooms in which a number of people are engaged on operations which are fairly simple to perform and do not require a very intense illumination. In practice one finds a large number of cases in which a general illumination of 2 to 3 foot-candles is used; it is unusual to find a uniform value exceeding 6 foot-candles. If more light than this is needed, we usually resort to local illumination. Spectacular illumination, which may reach 10 or 20 foot-candles, is an exception.

For work that requires an exceptional amount of light (5 to 50 foot-candles), or which involves great care and concentrating of mind on the part of the operator, local lighting is usually essential.

The chief advantages of local lighting are :—

(*a*) That the lights can be made adjustable so as to suit the needs of each worker.

(*b*) That a high illumination can readily be obtained.

(*c*) That the lights can be separately controlled, and in some cases this leads to an economy; *e.g.* when only a few people are in the room, so that only those lights need be turned on which are strictly necessary.

On the other hand, the provision of general illumination has usually the advantages of being :—

(*a*) Cheaper to install.

(*b*) Less trouble to clean and maintain.

(*c*) More or less independent of the position of furniture.

If general lighting is all that is necessary, one has a choice between using a powerful central source to light the whole room or distributed small units. If a few lamps of high candle-power are concentrated at one point in the room, we may expect a

certain gain in the efficiency of the illuminant. On the other hand, unless the room is a very small one, some difficulty may be experienced in distributing the illumination evenly, and the corners of the room are apt to be underlighted. Direct lighting from a central source is rarely satisfactory in this respect, and is apt to cause troublesome shadows. Indirect and semi-direct systems are usually more successful in distributing the light and avoiding shadows; but even in this case one would not usually try to light a room larger than 20 feet square by a single central unit. Other disadvantages of using a single powerful source are that the whole room must be lighted for the benefit of a single person, and that failure of a lamp plunges the room into darkness. For these reasons central units are usually subdivided, a number of lamps or mantles, separately controlled, being arranged in the one fixture.

In general, the method of spacing units of moderate candle-power at appropriate intervals gives the best results, and it is really only in quite small rooms that lighting from a single central point is utilised.

Natural and Artificial Light compared.

In considering the comparative advantages of local and general lighting, direct and indirect illumination, etc., one naturally turns to the study of daylight conditions. The evolution of the human eye has taken place in response to natural conditions; compared with the total period of existence of mankind upon earth, the few years during which artificial light has been available to any great extent appears infinitely small. The whole structure of the eye has been developed with a view to the best use of light from the sun. The brow and eyelids shade the eye from the intense rays overhead, so that we see only the illuminated objects and not the sun itself. The adaption of the pupil aperture and the retina enable the eye to adjust itself to the enormous variations in brightness met with in Nature. It is therefore argued that in artificial lighting one should strive to imitate natural light as closely as possible.

But it must be remembered that daylight is a very variable commodity. The light in London, where the proportion of sunlight during the year is unfortunately small, is very different from the intense brilliant light in the tropics. The shadows and

diffusion from a white sky are quite distinct from those characteristic of direct sunlight from a blue sky; and the sun shining through a light mist gives rise to intermediate conditions. There we have in daylight something analogous to direct, indirect, and semi-indirect lighting.

It is well known that one meets in Nature conditions that may be highly prejudicial to the eye. Incautious exposure to the intense glare of the desert, or to the sunlight in snowy mountainous regions, where the percentage of ultra-violet energy is exceptionally high, may give rise to inflammation of the eyes and even blindness. Moreover, it may be pointed out that many of our present occupations—reading, for example—are of

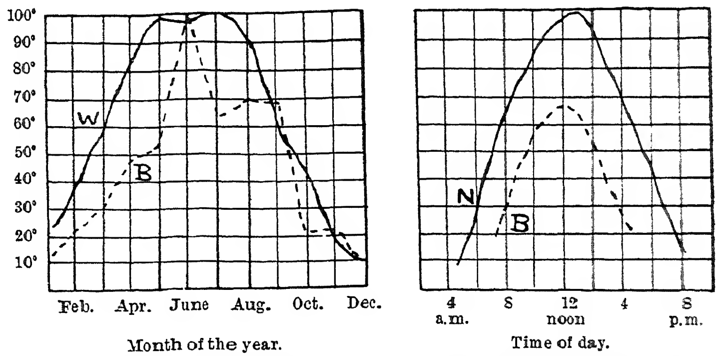


FIG. 148.—Variations of daylight during the day and at different seasons of the year, according to the researches of Weber (W) in Kiel, Basquin (B) in Chicago, and Nichols (N) in the Tyrol.

comparatively recent date in the history of mankind. It is doubtless true that the eye has developed itself so as to use to the best advantage daylight out-of-doors: but it does not follow that daylight entering a room from side windows is necessarily the ideal method of illumination. It need scarcely be pointed out how very variable indeed is the intensity of daylight during the year and at different times of the day; and how greatly it is affected by climatic conditions. There are times when the blinds must be drawn down to diminish the glare of direct sunlight. On the other hand, an unexpected fog may diminish the illumination so much as to make artificial light essential. This uncertainty is very inconvenient in many industrial operations. A case in point is afforded by the colour-matching industries, for which only the best daylight is suitable, and which are apt to be interrupted by changing climatic conditions. For such

work the systems of "artificial daylight" described in Chapter VI. would seem to have a future.

It will be seen, therefore, that in imitating daylight conditions some discretion must be used. Indirect illumination from the ceiling is frequently said to resemble daylight on account of the uniform illumination received. As a matter of fact the chief characteristic of an ordinary room lighted by side windows is the extreme irregularity of the illumination. The intensity on the desks in a school-room most remote from the windows, even where every effort has been made to secure abundant access of daylight, may be only one-tenth of that near the windows. In many buildings less well provided with window space the proportion might be even smaller.

As regards constancy and uniformity, artificial light has an advantage compared with daylight, and, being much more under control, is more readily adapted to specific occupations. It is evident that the ideal conditions of illumination for such processes as clerical work, drawing, sewing, printing, etc., may be widely different, and the artificial lighting can be varied accordingly. But it would not be easy to adjust the daylight in the same way.

The excellence of daylight for most purposes is probably due to two main factors. In the first place, the amount of illumination is, under favourable conditions, far in excess of that practicable by artificial light. An illumination on a well-placed desk of several hundred foot-candles is quite usual, and bright unrestricted daylight outside may give several thousand foot-candles. The adaptability of the eye enables it to work conveniently at values far less than this; but still the fact of having such abundant illumination at one's disposal is an advantage, and no doubt the human eye, being developed to suit daylight, is at its very best in these circumstances.

The second, and perhaps most important, factor is the perfection with which daylight is diffused over large surfaces. The illumination received in a room usually comes largely from the sky, and there is often a considerable component received by reflection from surrounding buildings. In general the real source of light, the sun, is not visible to the occupants of the room (or is screened by the blinds), so that absence of glare is a marked feature. The light coming from such a large area gives soft shadows and penetrates into every part of the room with a completeness not usually attained by artificial light.

Another factor that is still imperfectly understood, although its importance is fully recognised amongst medical men, is the effect of sunlight on the human body. It has been explained that the ultra-violet rays present in sunlight are believed to have strong germicidal action, and that rooms into which sunlight does not readily enter becomes harbouring places for germs and disease. So well is this recognised that in Holland the legislation forbids the employment of children and women in workrooms from which daylight is excluded. Sunlight is recognised to be a valuable weapon in combating tuberculosis, and it is said to have an important influence on the skin, heart, and respiration; for these reasons free access of daylight into interiors is essential, even in those cases where the technical requirements of the work are apparently completely met by the use of artificial light.

Having considered these preliminary points, we will now take up in turn various cases of interior lighting and show how they apply.

Domestic Lighting.

In the lighting of private houses taste plays a considerable part. In the houses of the poor, cost and utility are the chief factors. But in the homes of the wealthy the choice of fixtures may be guided almost entirely by artistic considerations, and the chief openings for the skill of the lighting engineer lie in the contrivance of dainty and pleasing effects.

The most convenient plan of considering the various problems of domestic lighting is to start at the entrance to the house, and then to take up in turn the lighting of the various rooms (hall, dining-room, drawing-room, etc.).

The first point that deserves notice is the provision of a suitable *light outside the front door*. This light should be placed above the doorway and well shaded, so that it throws sufficient light on the threshold but is screened from the eyes of the person opening the door. Such a light serves to guide the steps of the departing guest, and is also sometimes useful in enabling the lady of the house to scrutinise undesirable callers before admission. It may be suggested that a light strong enough to give at least 2 foot-candles on the door-step might well be used. With a proper form of shade this would probably require a lamp of 30 to 50 candle-power.

It may be observed that the utility of such a light is enhanced considerably when the step is well whitened. If the tone of the step is similar to that of the path below it, its outlines will be difficult to distinguish even with a fairly bright illumination. The name or number of the house should preferably be illuminated so as to be visible at night. In the case of many houses the name is indicated on the glass above the front door, and is lighted up by the light in the hall. The name should be backed by some form of diffusing glass, so as to give a good luminous background. At present there is seldom any systematic attempt to provide for the lighting of the names of houses, and they are not infrequently left in complete darkness. Anyone who has attempted to locate an address in an unfamiliar suburb at night will appreciate this remark. In the United States this illumination of name-plates has been encouraged by the electric supply companies, and in some cases special rates for "all-night" porch lights have been allowed.

The "*hall*" is a somewhat dubious term, and may indicate either a comparatively small lobby, where hats and coats are removed, or a more pretentious apartment giving access to the drawing-room and dining-room. In the former case single lights of moderate candle-power, giving a general illumination of 1 to 2 foot-candles, would usually suffice. The walls should preferably be light in colour, so that the light may be thoroughly diffused into the corners, and umbrellas, hats, and garments readily distinguished. Some form of diffusing pine or globe may be used, and heavily obscured antique lanterns are preferably avoided.

In the case of halls of a more imposing character, one's choice usually lies between a chandelier and a globe or inverted bowl-fitting (either direct or indirect) hung by chains from the ceiling. From the lighting standpoint the latter is usually preferable. It seems probable that this type of fitting will replace chandeliers to a great extent in new houses; but in old mansions there are often massive antique fittings which are retained for their decorative appearance. The conversion of these to electric light often calls for considerable skill. A form of chandelier which should certainly be avoided is that in which the lamps are tilted at an angle and provided with reflectors that throw the light into the eyes of people seated round the room. In view of modern improvements in shades and globes, there is no longer

any need to incline the lamp in this way, and a suitable type of globe or reflector can be selected according to the amount of light it is desired to allot to the upper parts of the room. In general the lighting of a hall calls for fairly uniform illumination, but there are frequently pictures which call for special treatment. A well-diffused light and fairly soft shadows are desirable. It is well to allow a comparatively large amount of light to the upper part of the room, so as to show up mouldings, pillars, and other architectural features.

FIG. 149.—Conventional dining-room lighting. Well shaded light over table and subdued surroundings.

In the *dining-room* it is generally recognised that the table should be the centre of interest, and that the surroundings should be comparatively subdued. The table is conveniently lighted by a single silk shade (which may have within it an appropriate prismatic or white reflector). This should be hung at a sufficient height not to interfere with the view looking across the table, and the shade should be just deep enough to screen the light from the eyes of people sitting around it; it should, however, not enclose the lights so completely as to prevent the more remote parts of the table being properly illuminated. These shades are usually made of some coloured warm-looking material, but they should be lined with white silk, so as to reflect a maximum of light on the table. The surroundings, although subdued, should not be obscure. The illumination on the table may well be 3 to 5 foot-candles: 0·5 to 1 foot-candle would probably suffice for the rest of the room. The amount of this general lighting will naturally depend on the nature of the surroundings. In dining-rooms, wall-papers having a reflecting coefficient of about 20 per cent. or less are often employed.

To provide this a central cluster of lamps on the ceiling,

in conjunction with the shaded lamp, is sometimes employed. This combination is a usual one in middle-class houses. In very much larger rooms more elaborate fittings, such as chandeliers carrying prismatic glass globes or crystals, are sometimes used.

The light of a dining-room is naturally affected by the use to which the room is put. Many people use these rooms for other purposes during the evening, and there may be desks in corners of the room which require local illumination. In the case of electric light plugs and portable lamps should therefore be provided. It is not unusual to provide bracket lights on either side of the fireplace. Sometimes these take the form of imitation candles, screened with silk on the side remote from the wall. But the method is a decidedly inefficient one, especially when the wall-paper is dark in tint.

More or less bulky arm-chairs are sometimes placed near the fire, and bracket lights may then be desired. In a narrow room the result of introducing such furniture may be that the table will not be central. In this event a fitting suspended from the centre of the ceiling may fall over the side of the table instead of over the centre, making the distribution of illumination uneven and bringing the lamps within the range of vision of the people nearest them. If this displacement of the table cannot be avoided, it is perhaps better to abandon the idea of using a suspended shade and, if the ceiling is light in tint, substitute a semi-indirect fitting at a higher level.

In the *drawing-room* taste plays perhaps a greater rôle than in any other. The lighting problem is usually simplified by the fact of the walls and ceiling being light in tint, and there should be no difficulty in providing a well-diffused and even illumination. But on this point individual tastes differ. Some people, who entertain a great deal and constantly use the drawing-room for dances, receptions, or other social affairs, like a decidedly brilliant and festive illumination. Probably they are partial to the glitter of cut-glass and polished metal fittings, and are anxious that the pictures, china, or other treasures in the room should be seen and admired. Others prefer a cosy and subdued effect and make liberal use of silk shades; they like to have only a very mild illumination, and would probably confess that the firelight alone provides the most favourable condition for a confidential chat.

The best method of meeting the varied demands in a modern drawing-room would seem to be to provide for various alternative systems of illumination. For example, a central fitting may contain several lamps, so that either a brilliant or a moderate general illumination can be secured. In addition there may be *well-shaded* bracket lights, or portable lamps equipped with silk shades. In the ordinary course these may provide all that is required, and will give the desired "cosy" and restful effect. But on special occasions, when it is desired to flood the room with light, the central fitting can be turned full on: a general illumination of 3 to 5 foot-candles may in this case be provided. A large drawing-room not infrequently extends into alcoves and recesses, and these require special local treatment. The general illumination may be devised so that they are in partial soft shadow. This gives variety to the room as a whole and marks off these areas as separate "cosy corners," into which those who desire a *tête-à-tête* conversation, or who wish to enjoy some game or occupation without disturbing the other people in the room, can withdraw. Such recesses are useful in a ballroom for couples who wish to sit out. The idea that such recesses form in a sense separate apartments can be accentuated by using appropriate and distinctive local lamps. Another possibility (seldom exploited, however) is the use of tinted lamps, so as to give a variation in colour.

In drawing-rooms of moderate size the choice of pendants or wall-fittings is largely a matter of taste. The latter are serviceable for adding to the general illumination, but they are usually not very conveniently placed if a person desires to use their light for reading. This is illustrated in fig. 150. The people seated round the fire naturally tilt their books, so that they can receive very little light from the wall-fittings, which are also in the direct range of sight. On the other hand, the light from the central fitting and the reflected light from the ceiling, coming over the shoulders of the people, is admirably adapted for reading purposes. It often happens that a drawing-room is lighted on the "subdued" principle, but nevertheless contains several tables where people habitually read and write. For this work the customary illumination for this purpose—about 3 foot-candles—should be provided, and it is conveniently furnished by portable well-shaded lamps.

It is of interest to give some idea of the brightness of the walls necessary to give a "cheerful" impression. From date

taken in a large number of installations, the authors are disposed to suggest that a surface brightness of the wall-paper should be about 0·3–0·5 foot-candle. The corresponding amount of illumination to be allotted will naturally depend on the reflecting power of the paper used. In order to show up small pictures, friezes, china, etc., an illumination of not less than 1 foot-candle is usually necessary; with the light greys, greens, and pinks

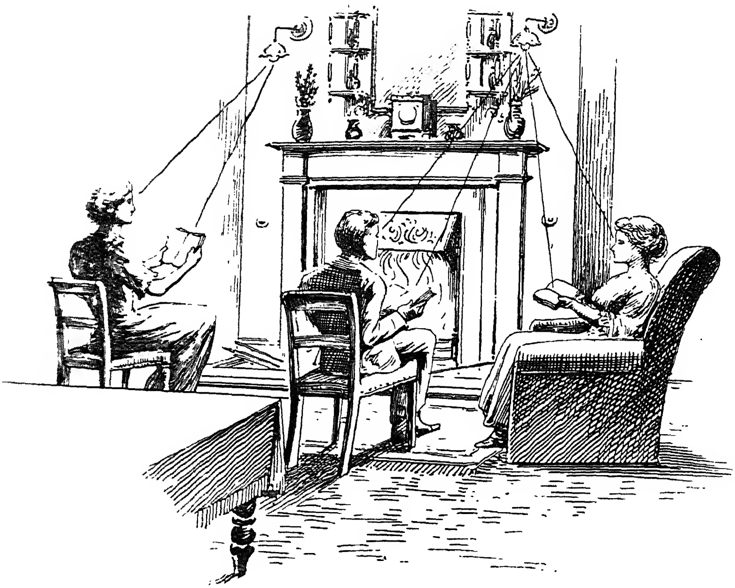


FIG. 150.—This shows the effect of imperfectly shaded bracket lights. The light strikes direct into the eyes of the reader and only reaches the page of the book at oblique angles.

commonly used for papering drawing-rooms, this would give a surface brightness of about the value quoted above.

It is too early as yet to dogmatise as to the value of direct, indirect, and semi-indirect lighting in a drawing-room. In the writer's experience most people dislike the effect of pure direct lighting, but regard semi-indirect methods more favourably.[1] A very serviceable method of lighting fairly large rooms is a combination of a central semi-indirect unit with wall brackets. The latter should be well shaded, and the candle-power of the lamps should not in general exceed 10 to 15 c.p. The system of

[1] See "Direct and Indirect Lighting in a Small House," *Illum. Eng.*, London, Nov. 1913, p. 573.

"cornice lighting" by lamps concealed round the cornices of a room, while it has a value for spectacular lighting in large interiors, does not seem well adapted to a small drawing-room. In such cases the method of spacing lamps at intervals gives rise to a somewhat "patchy" and uneven effect, and with the present appliances the effect is not so good as that derived from well-designed central illumination.

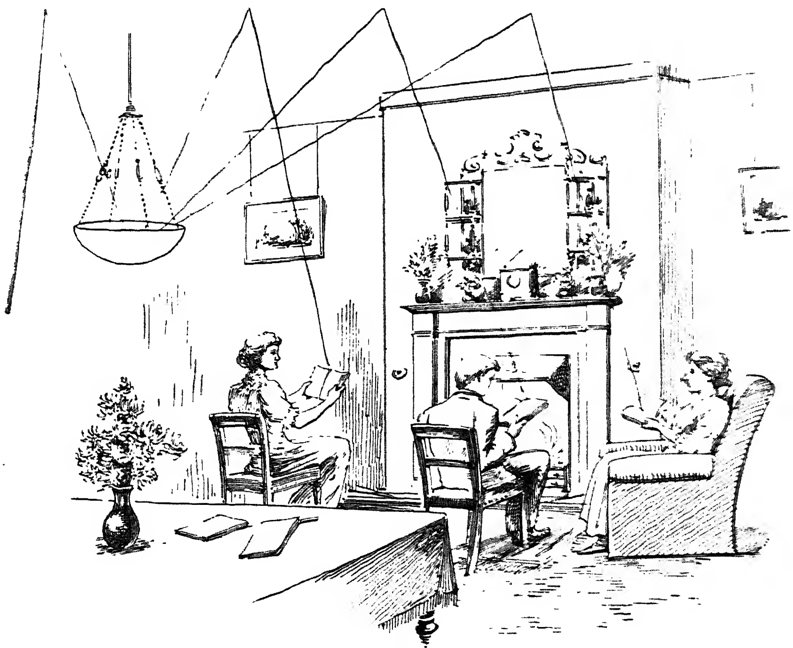


FIG. 150A.—With a central unit, directing a considerable amount of light on the ceiling, the reflected rays come over the shoulders of the readers, illuminating the book at a much better angle. The actual source is quite out of the direct line of vision.

There is also room for ingenuity in the *lighting of verandahs*, which make pleasant reading-places on a summer evening. A few well-designed bowl-fittings suspended among the pillars have decidedly attractive effect, seen from the garden. When the verandah is electrically lighted and opens out on to a terrace walk, it may be worth consideration to lead out a wire to a substantial plug, so that special outside lanterns can be rigged up at short notice for fêtes and garden-parties.

A few words may be said on the lighting of *billiard tables*,

hich now seems to have become a fairly standardised process. In this case the nature of the game makes careful lighting a practical necessity. Possibly this explains why judicious methods of lighting billiard tables were already in common use at a time when lighting problems in general received little attention. The system now used for a full-sized table requires six symmetrically placed lights of 50 to 60 c.p., which are completely screened from the eyes of players by conical cardboard

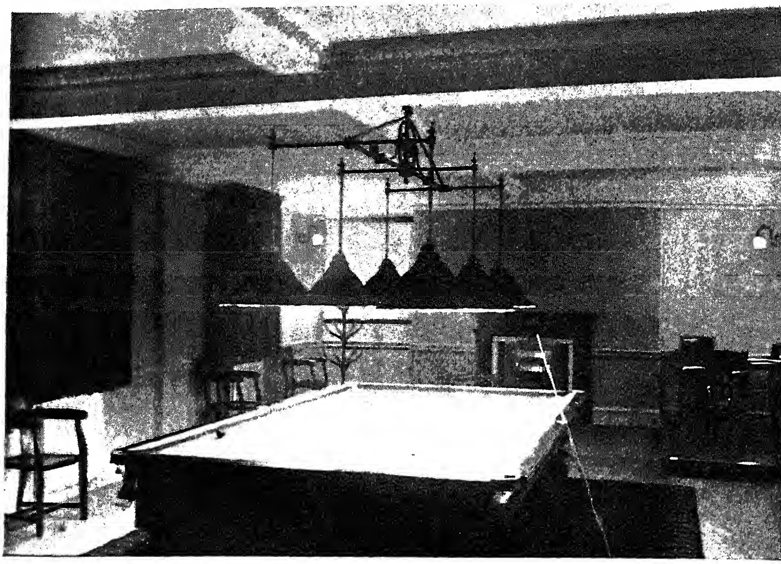


FIG. 151.—Typical billiard-table lighting by six 55-watt electric lamps in cardboard shades.
(Illumination 16–20 foot-candles.)

shades. By this means an even illumination of 15 to 20 foot-candles can be secured. This high value is apparently necessary in order that a player may get a good view of a ball at the other end of the table. It is usual to supplement the table lighting by a few brackets round the room. The contrast of the brightly lit cloth with the subdued surroundings seems to be preferred to a high general illumination, and doubtless helps to concentrate attention on the play.

The illumination of *libraries* will be discussed shortly. There are in most houses rooms devoted to study, or where children do their lessons, which require to be lighted in a similar way.

The illumination on desk or table should not be less than 3 foot-candles, and the light should be well diffused, so as to avoid, as far as possible, inconvenient reflection from shiny papers.

It is hardly necessary to add that proper methods of screening the lamps from the eyes are most essential. A small library or study (say, 12 to 15 feet square), such as would be found in a middle-class home, can be quite well lighted from a central outlet. With direct lighting several well-shaded lamps or burners should preferably be used, being more favourable to good diffusion and soft shadows than a single source. The lighting of the shelves should not be forgotten. An illumination of 1 foot-candle should be sufficient to enable the titles of books to be clearly read, and it is usually possible to select reflectors which, while concentrating most of the light on the table, also provide sufficient to illuminate any shelves round the room.

A great deal is said nowadays on the illumination of school-rooms, and the harm done to the eyes of children by working with deficient light. But it must be remembered that even when the illumination in the school-room is good, there remains the possibility that children may damage their sight by constant reading in a poor light at home. This is the more liable to happen because children, in order to escape attention, frequently settle down in a corner of the room where the light is generally least. A responsibility rests with parents in this matter: many people consider that home lessons are a mistake, and that young children should not be encouraged to read much in the evening. It is at least possible to see that such reading is done under favourable conditions.

The requirements of *bedroom* lighting may be readily stated. The place where the light is most needed is naturally the dressing-table, and the illumination on the table should be high—5 foot-candles is a very general figure. The light is usually provided by two local pendant lights. Such lights are necessarily somewhat near the eye, and must be arranged to throw a strong light on the face. A good diffusing translucent shade which just covers the mantle or filament is therefore desirable. Two lights, one on either side of the table, are generally supplied. A single lamp only may be provided for reasons of economy, but it is not so satisfactory, since "unidirectional" light tends to leave part of the face in shadow.

If, on purely economical grounds, it is only proposed to

install a single outlet in a bedroom, it is probably best that this should be located over the dressing-table. But it is obvious that this does not completely meet the requirements. For example, a lady while dressing wishes to examine her full-length appearance in the wardrobe mirror from time to time. Now, the dress she is wearing will probably have to stand inspection in the strong illumination of the ballroom, or at an evening party. To judge of its effect, therefore, she requires an equally good illumination in her own room. It is hardly to be expected that the full figure of a person standing in the centre of a room can be properly illuminated by the local lights of the dressing-table, and there are also other objects about the room—the washing-stand, for example, which require more illumination than these lamps can be expected to yield. An additional central light may therefore be desirable.

Many people follow the practice—not approved by the medical profession—of reading in bed. Its prejudicial effects are doubtless partly due to the fact that the illumination is so often deficient. A local light, mounted on a bracket above the bed, or a well-shaded portable lamp at the bedside should be provided. This lamp should be so arranged that it can be lighted or extinguished by the person in bed. This enables him to have some illumination in the room while retiring and to obtain a light readily should he wish to get up during the night-time. If the room is lighted electrically the lamp should have an easily accessible switch. A gas lamp should have a by-pass; and if placed out of reach on the wall above the bed may be controlled by pneumatic or electric means.

A bedroom is usually arranged on a very definite plan, and the best position for beds, dressing-table, etc., is therefore fairly clear. Nevertheless it sometimes happens that the furniture is changed, so that lights fall quite in the wrong positions. It is unfortunate that these rooms are so often wired by the contractor before the position of objects has been settled. For example, judging that the dressing-table will be placed near the window, he will provide an outlet on the ceiling, the position of which has to be guessed at; yet a few inches one way or the other may make a great difference to the utility of the lights. Sometimes the servants find that they need more space behind the table and push it further into the room. The lights may then be found hanging *behind* the plane of the mirror and throwing most of their light on the floor.

In bedrooms—particularly suites in hotels—there is always the possibility that the positions of furniture may be altered. This is one argument in favour of well-diffused central lighting.

The other rooms in a house all furnish their respective problems. It is curious how often the lighting of the *kitchen* area is neglected. One would think that the lady of the house, knowing how intimate is the connection between good light and cleanliness, darkness and disorder, would make it her special care. Domestic servants sometimes profess an obstinate belief in the oil lamp, especially for serving, declaring that the electric light "tries their eyes." This is probably due to the fact that the kitchen lighting is so often carried out in such a casual inefficient manner.

It should be remembered that the kitchen in the average middle-class home is used by the servants all day and for many different occupations—some of which require a decidedly high illumination. Cooking is done on the range and oven, dishes are laid out on the table, and reading and sewing may fill up the evening. The chief points where illumination is required are the ovens, the table, and the dresser. In addition, there are usually a number of deep cupboards which are constantly being used and into which light must enter.

These conditions seem to suggest an opportunity for a cheap but well-designed semi-indirect unit. In any case the ceiling and papering of a kitchen should be very light in tint, so as to diffuse the illumination. In addition, good local lighting by a well-shaded lamp should be available for sewing and reading in the evening. There seems little doubt that local lighting *is* preferred to general illumination for needlework—because such work really needs an exceptionally high illumination, and possibly also because the fact of illumination on the work being greater than the brightness of surrounding objects, aids the eye and mind by concentrating the attention. The arrangement of the lights must naturally depend on the size of the kitchen and the kind of the work done. But as a fairly successful method of meeting these requirements in a middle-class home one may suggest:—

(*a*) That the walls and ceiling should be invariably light in tint.

(*b*) That a lamp, well shaded by a translucent reflector, should be fixed centrally above the kitchen table. The position of this may be adjustable, so that it provides general illumination and throws light on the grate and oven; and when lowered it should give the local illumination prescribed above.

(c) That a light, also well shaded, may be needed to illuminate the dresser, and to assist the general illumination of the cupboards in the room.

Many of the above remarks apply to the pantry and the scullery. It is, again, astonishing that these rooms should be so frequently underlighted. When the china or silver are served they are placed in a strong light on the dining-table, *and their appearance is judged by an exceptionally brilliant illumination.* Surely, therefore, an equally good illumination should be provided in the rooms where the cleaning and polishing takes place! A point that deserves special notice is the need for a good illumination over the sink, for washing-up. A claim may also be made for a light in the *coal-cellar.* It is decidedly awkward for a servant to carry in a lighted candle every time coals are needed. Shades liable to be spoiled by deposits of coal dust of course should be avoided, but there are many varieties of metal reflectors that are suitable for this purpose.

Mention of the coal-cellar leads us, by a natural process, to speak of the *bathroom.* One would naturally select materials able to withstand a steam-laden atmosphere, and, in the interests of cleanliness, a good well-diffused illumination is clearly needed. In modern bathrooms it is happily becoming usual to employ white- or cream-tiled surfaces and distempered walls which reflect the light well, and in a small room a single central source will give all the illumination needed, say, 2 to 3 foot-candles. In larger rooms it may be desirable to add a local unit over the wash-stand and mirror.

On *stairs, corridors, and landings* an illumination of 0·5 to 1 foot-candle suffices for all ordinary purposes. When a number of rooms open on to a large approximately square landing a somewhat higher value may be preferred, and is sometimes desirable for decorative effect. A semi-indirect unit is well suited to these conditions.

Finally, the consumer may be advised not to exercise too strict an economy in the number of outlets. By limiting the number of points by which gas or electricity can be taken the first cost of an installation may be reduced; but this apparent saving is often more than compensated for by increased consumption. By suitably subdividing the lighting one can arrange to use just those sources that are strictly necessary; and it is often convenient to have several alternative methods of illumination.

THE LIGHTING OF CLUBS, HOTELS, AND RESTAURANTS.

Having dealt with domestic lighting, we may turn to the lighting of clubs, hotels, and other classes of buildings, where substantially the same problems recur.

Clubs and hotels contain dining-rooms, reading-rooms, bedrooms, etc., just as does a private house. The chief distinctions are that the rooms are in general larger, and that whereas in a private house the owner may arrange the lighting to suit his personal taste, the committee of a club or the manager of an hotel have to study and satisfy the public.

There is little doubt that the lighting of some London clubs is both uneconomical and unsuitable, particularly the older institutions, which are not infrequently conservative and reluctant to make changes. A recent writer has remarked that the subtle sense of discomfort pervading the average club reading-room or smoking-room is to be traced mainly to the glaring and inconvenient systems of lighting employed. Old-fashioned, low-hanging chandeliers are often used, and the reader, whatever position he adopts, finds it well-nigh impossible to avoid the glare of the bare metallic-filament lamps with which they are bespangled. Such fittings are also apt to throw multiple shadows of one's head, which are only avoided by tilting one's paper at some highly inconvenient angle. Very often too the lights on the staircases and in the corridors are badly placed and insufficient, so that the interior as a whole assumes by night a decidedly gloomy appearance.

Similar remarks still apply to many hotels. Yet one would imagine that in clubs and hotels, of all other institutions, the lighting would be the subject of special care, for the expense involved in providing good illumination is usually a trifling fraction of the total annual turnover.

It must be remembered that the evening hours, spent under artificial light, form a considerable portion of the time during which visitors occupy the hotel. In the daytime people are mainly occupied with business or sight-seeing; in the evening they will probably dine at the hotel and subsequently spend a part of the evening in the lounge or smoking-room. If, during these hours, they are subject to the petty irritations of poor lighting, if their time is spent in the midst of glare or forbidding semi-darkness, they bear a grudge against the hotel afterwards. If, on the other hand, all the rooms are cheerfully and comfortably

lighted, the impression they carry away will probably be a favourable one.

One finds in the lighting of restaurants scope for a nice appreciation of the kind of custom for which it is intended to cater. In some cases the intention is to provide for people who merely make a casual visit in order to get light refreshments, stay a short time, and then take their leave. A strong general illumination is here considered necessary, in order that the manager may be able to take in the room at a glance and ensure that no customer in any quarter will be overlooked. The customer, on his part, usually prefers a bright, cheerful illumination; very probably he comes in alone and likes to look around him while taking his meal.

But there is another branch of business which is quite distinct, namely, providing for the needs of diners who really utilise the meal as an opportunity for meeting friends and sustained conversation. Under these conditions there is not the same necessity for speed. Dining proceeds in a leisurely manner, and a bright general illumination is not always desired. Customers prefer a subdued local illumination of a "cosy" character, the tables being frequently set in little alcoves; this is conducive to a private talk, and promotes a feeling of restfulness and comfort. This method is very generally employed in restaurants of a high class, and lends itself to very artistic effects. The impression derived through the eye is regarded as an essential part of the pleasure of such a meal.

The Lighting of Banks and Offices.

Offices may be divided somewhat sharply into two main classes. There are, firstly, those in which a considerable number of operators work side by side and are engaged in doing substantially the same class of work—probably of a more or less routine character, and by no means exacting to the practised hand. In this case it may be assumed that each worker requires substantially the same conditions of illumination, and general lighting is conveniently used. Each desk should receive at least 2 to 3 foot-candles—probably, seeing that clerks deal with handwriting rather than printed characters, 3 to 4 foot-candles might be even better. The lights should be arranged systematically, so as to give even illumination; they should be well shaded and preferably hung at a high level, so as to be outside

the direct range of vision. With a view to avoiding inconvenient shadows, the walls and ceilings should be light in tint. Semi-indirect lighting seems to be coming into favour for offices of this kind, and has the advantage of diminishing the "shiny reflection" from the glazed paper of ledgers, etc., largely used for clerical work. In legal offices, where stacks of japanned boxes, or rows of pigeon-holes containing documents will usually be found, good diffusion of the rays from the light walls and ceilings is a distinct help. Lamps should be so placed that no dark shadows are thrown inside such recesses, and their contents should be strongly and evenly illuminated. The absence of dense shadows is also an advantage in working with files or papers, card-indexes, etc.

Smaller offices, containing several desks or tables where a few people only are at work, may require somewhat different treatment. In this case a good general illumination of, say, 1 to 2 foot-candles all over the room is usually desirable, and here again a central semi-direct unit is often advantageous, especially where the walls are lined with shelves, maps, etc. But it will usually be found that the desks or tables at which the workers are seated require some local lighting. In the case of work requiring much concentration this extra light is fully appreciated.

Care should be taken that such illumination, besides being sufficient, should come from the right direction. A typist, for example, prefers a lamp so placed that it illuminates the keys of the machine and also the manuscript on her left. Light coming from the front would be obstructed by some forms of typewriters and would leave the keys in shadow. Direct light coming from immediately overhead is particularly objectionable, as it almost invariably casts a shadow from the head of a person bending over their work.

Similarly, in desk lighting, a light from directly above or slightly behind the worker is apt to be inconvenient. Probably the best position for a desk light is in front of the worker and to the left, so as not to cast a shadow of the writing hand. An illumination of 3 to 4 foot-candles may be suggested. Such local lights are preferably screened by an opaque shade.

The lighting of a draughtsman's office is a special problem, but as drawing-boards are so frequently used in the offices of architects, surveyors, and engineers, it may be well considered in connection with office lighting. For such work the illumina-

tion of inconvenient shadows cast by the head, hand, or drawing instruments is an important factor. Indirect and semi-lighting seems to afford a method of avoiding such shadows, and is frequently recommended for drawing-offices for this reason. On the other hand, some draughtsmen prefer a well-shaded local and adjustable light, placed above and in front of them, and there are others who contend that the best light of all is that furnished from a small shaded lamp attached to the forehead.

FIG. 152.—A view of the London and South-Western Bank at Fenchurch Street, showing local lighting with Holophane bank desk units.

The stooping position necessarily assumed by the draughtsman makes back and overhead direct lighting of little service, since these methods invariably give rise to bad shadows. Some difference of opinion exists as to the intensity of illumination required. For plain work 3 to 4 foot-candles would doubtless suffice, but in tracing fine lines a value up to 10 foot-candles might not be excessive. The desirability of being able to alter the intensity of illumination according to the character of the work is one argument in favour of an adjustable local light for drawing.

The lighting of banks is almost invariably carried out by local lights, and these seem to be preferred by the workers. It

is perhaps natural that such lights should be preferred at the counters, where the clerks have to examine cheques and signatures with care. It is not quite so clear why the method is preferred to general lighting in the main offices. In many of the city banks the plan adopted is to provide a moderate general illumination from globes or bowls hung from the ceiling, and to have local lamps over each desk as well. In fig. 153 we reproduce a photograph showing a highly novel method of

FIG. 153.—A view of the Swedish-American Bank in Chicago.

The illumination comes from lamps in X-ray reflectors which are concealed in the eight boxes over the tellers' desks, whence they throw their light upon the ceiling.

lighting introduced into the Swedish-American and other banks in Chicago by the National X-ray Reflector Co. The lamps are completely concealed from view in troughs or boxes along the bank rail over the tellers' desks; these throw their light upwards on the ceiling. There are also lamps placed above the glass skylights.

There seems room for improved forms of standard lamps for desk lighting. The best height for the lamp, the form of shade, the spacing for even illumination, and the avoidance of inconvenient reflection from shiny paper are all points that

require consideration, and it should be possible in course of time to arrive at standard practice in this respect.

There is clearly a responsibility on the part of the employer to see that the eyes of those working under him do not suffer through carrying out an exacting occupation in deficient or badly arranged light. From a purely economical standpoint it is also wise to provide good conditions of illumination. For it can be readily understood that clerks working by insufficient light. and suffering constant inconvenience as a result, are much more apt to make a slip than if the illumination were adequate; and it is highly probable that a direct connection could be traced between the frequency of such errors and the conditions of illumination. In an occupation where a high degree of precision and accuracy must be maintained, and where a slight slip may have serious consequences, expenditure on proper lighting is merely judicious insurance.

There is another side to bank lighting. Good illumination, like handsome furniture, is an excellent advertisement. The interior of a bank should be imposingly furnished and decorated in order to impress casual clients with a sense of its prosperity. A system of lighting by units suited to the dimensions and style of the interior aids this impression, while "makeshift" inadequate arrangements may create a subtle feeling that it is not, after all, such a very prosperous and well-managed concern.

School Lighting.

Allusion has been made to the folly of allowing children to read at home in a poor light, and the responsibility that rests upon the parents in this matter. But the responsibility of school authorities is greater still. The reading done by children in the home is optional, but their attendance at school is compulsory. It is therefore the duty of the school authorities to ensure that the lighting is well adapted to the needs of the children, and no consideration of expense should be allowed to weigh against their welfare.

For many years it has been common knowledge among medical authorities that the eyesight of children undergoes deterioration during school-life. In Germany, where state education on a large scale was probably adopted sooner than in any other country, the evil ran to great lengths, and the authorities have since been making herculean efforts to trace and remedy

the defects responsible. But experience has been similar in all countries. In 1908 a mass of statistics was published in the *Illuminating Engineer*, London. Everywhere experts told the same tale. The percentage of children having defective vision rises steadily from a comparatively low value in the infants' class to a considerable figure, 20 to 30 per cent. or even more, in the most advanced classes.[1]

Each child that is allowed to grow up with impaired vision means a serious loss to the nation. He is handicapped directly by his poor eyesight and indirectly by the imperfection in his education necessarily caused by this defect. It is probable that a considerable number of the cases of total blindness developed in middle life could be traced to straining the eyesight in childhood.

Medical authorities offer several explanations for this fact. It is generally believed that the tasks given to young children involve too much close work. A committee appointed by the British Association has issued explicit directions as to the size of type permissible for children of various ages, the quality of paper to be used, and the spacing of the lines of printed matter. Dr James Kerr, Medical Officer to the London County Council, has recently gone a step further and advocated that no reading should be done before the age of seven.[2]

But after allowance has been made for any such defects in our educational system, the fact remains that their prejudicial effect is accentuated by insufficient or wrongly arranged illumination. The difficulty of making out print by a poor light is well known to the adult; but in the case of a child, to whom the characters are more unfamiliar, it is still more pronounced, and may lead to fatigue even if the eyes are not injured.

A "normal person of middle age," Dr Kerr remarks, "will distinguish characters with greater readiness than a small child, because the characters are more familiar to the adult. Conversely a child requires better light to read by than an adult, to whom reading is second nature."

In considering the lighting of schools, it is convenient, first, to say something on the daylight illumination. The importance

[1] *Illum. Eng.*, London, vol. i., 1908, pp. 58–69.

[2] Paper read before the International Congress on School Hygiene held in Buffalo, August 1913. At this joint congress with the Am. Illum. Eng. Soc., a number of interesting papers on school hygiene were read.

of this subject was early recognised in Germany. Much valuable pioneering work has been carried out in that country by Cohn, L. Weber,[1] and others. The subject was dealt with in a paper before the British Illuminating Engineering Society by Dr Kerr in 1911.

The chief difficulty in studying the daylight conditions in school-rooms arises from their extreme variability. In Chapter VII. we have explained some methods of relating the illumination on the desk to the unrestricted illumination out-of-doors. From a practical standpoint the chief points that require attention are the dimensions of class-rooms and the allocation of the window space. A number of books on school planning have recently been published.[2] It is now generally recognised that it is best for light to come from the left, as in this case no inconvenient shadows are cast by the right hand in writing. Authorities differ as to the desirability of windows at the back and on the right as well. And for some years a spirited discussion has been raging between the advocates of "unilateral" and "bilateral" lighting. Most authorities think that windows at the back of the room should be avoided. They tend to cause inconvenient shadows from the bodies of children bending over their work, and the glare of a bright sky is apt to be troublesome to the teacher. There is a general recognition that windows facing the scholars should be avoided.

Assuming that the room is lighted solely by windows on the left hand, it is obviously desirable that the room should not be too deep, since the light diminishes so rapidly as we move away from the windows. Long and narrow rooms are recommended by some. The modern practice of the London County Council is to use class-rooms approximately 20 feet square. As a rough rule, the ratio of window space to floor area should not exceed 1:5. In practice, as large an area of the left wall as possible

[1] L. Weber, *Die Tagesbeleuchtung der Städtischen Schulen in Kiel* (issued by Kiel Municipal Authorities, 1908) and *Resultäte der Tageslichtmessungen in Kiel* (1905–1908, published by Schmidt and Klaunig, Kiel).

[2] *School Planning at Home and Abroad*, by W. H. Webb, 1911; *The Planning of Schools*, report by George Reid, County Medical Officer of Health for Stafford; *School Hygiene*, by Dr E. R. Shaw (Macmillan & Co., New York), 1911. A number of papers have also been read before the International Congresses on School Hygiene, and particularly that taking place at Buffalo in 1913. Other articles are to be found in German technical journals, such as the *Zeitschrift für Schulgesundheitspflege*; a list of references to Continental literature was given by Dr James Kerr in the *Illum. Eng.*, London, for Jan. 1914.

above the level of the desks is devoted to windows. The most valuable portion of the window is the upper section; windows should therefore be carried up nearly to the ceiling. It is also of great importance that the ceilings of school-rooms should be white, and that the upper portion of the walls should be light in tint. This helps to diffuse the light, and mitigates to some extent the unevenness of natural illumination. Blinds of a light tint should also be provided. They are sometimes necessary during the daytime in order to screen the direct rays of the sun; and when drawn down in the evening they are of material assistance in reflecting artificial light back into the room.

The question of daylight illumination in schools has been considered by the Joint Committee recently appointed by the Illuminating Engineering Society of London, whose report on this subject has just been issued (July 1914).[1] The natural lighting of school-rooms is of extreme importance in view of the fact that such a large proportion of school work is done in the daytime; there are some occupations, such as fine sewing, which, it is recommended, should only be done by natural light. On the other hand, the artificial light, while comparatively little used in the summer, is of importance during the winter time, especially in northern latitudes. Dr Max Oker Blom,[2] of the University of Helsingfors, points out that there are schools in some parts of Finland where the sun does not rise at all for two months during the winter. There are also in many schools additional adult classes during the evening, where artificial light has to be used.

Previous to 1908 quite a number of tests on the artificial lighting of school-rooms had already been carried out and were described by various medical officers in the *British Medical Journal*. As a rule, these observers did not furnish results of illumination measurements, but merely classified the conditions by the eye into "good," and "bad," and "moderate." A more complete investigation was carried out in the schools of Munich by a Commission appointed in 1907, and the results of many of these measurements have been summarised by Dr E. Schilling.[3] It is of interest to note that on this Commission both electrical and

[1] *Illum. Eng.*, London, vol. vii., July 1914.

[2] *Archiv f. Schulhygiene*, Jan. 1911.

[3] *Indirekte Beleuchtung von Schul- und Zeichesälen mit Gas u. Elektrischen Bogenlicht* (Oldenbourg, Munich, 1907).

gas engineers and oculists took part. Some tests of school-rooms in Boston were also described in a paper before the American Illuminating Engineering Society by Mr B. B. Hatch in 1907.[1]

A series of experiments on some electrically-lighted schools in New Jersey was subsequently described by Messrs G. W. Knight and A. J. Marshall in a paper before the American Illuminating Engineering Society in 1910. It may be noted that the school-rooms were apparently somewhat longer than those customary in London, being approximately 23 by 30 feet. An illumination of $3\frac{1}{2}$ foot-candles was obtained on the desks, the corresponding consumption of electricity being approximately 0·85 watt per square foot of floor area.

The question of the artificial lighting of schools was very fully discussed at a meeting of the Illuminating Engineering Society in London in 1911, when a paper on this subject was read by Dr N. Bishop Harman. The authors of this book also presented the results of a series of tests in public and elementary schools and colleges in London, and similar data were given by other members of the society. These results, covering as they did schools lighted by both electricity and gas lamps, have proved most valuable as a means of suggesting practical recommendations. Many defective installations were recorded. The tables and diagrams presented occupy too much space for reproduction here.[2]

After this meeting the Illuminating Engineering Society decided to appoint a Joint Committee, on which representatives of the Society and of the following other bodies were invited to act: The Association of Technical Institutions, the Association of Teachers in Technical Institutions, the London Teachers' Association, and the Medical Officers of Schools' Association were represented. This Committee issued a preliminary report on Artificial Lighting in 1911,[3] which will doubtless be followed by more complete recommendations later, and which has received widespread notice. The following are some of the most important recommendations:—

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[1] *Trans. Illum. Eng. Soc. U.S.A.*, vol. ii., 1907, p. 359. See also a Report of the Committee of Oculists and Electricians appointed in Boston, and published by the Municipal Printing Office in that city in 1907.

[2] See *Illum. Eng.*, London, vol. iv., 1911, pp. 157–166 ; 203–242 ; 289–298.

[3] *Illum. Eng.*, London, vol. vi., July 1913, p. 364.

(1) *Amount of Illumination.*

(*a*) *Desk Illumination.*—(*a*) For ordinary clerical work (reading and writing, etc.) the minimum illumination measured at any desk where the light is required should not fall below 2 foot-candles. (*b*) For special work (art classes, drawing offices, workshops, and stitching with dark materials, etc.) a minimum of 4 foot-candles is desirable. (*c*) For assembly rooms, etc., and for general illumination, a minimum of 1 foot-candle measured on a horizontal plane 3 feet 3 inches from the ground.

(*b*) *Blackboard Illumination.*—In rooms where students are distant more than 20 feet from the blackboard, and where it is customary to use diagrams in coloured chalk, an illumination on the blackboard of 60 per cent. in excess of that in the rest of the room is desirable. The board should be maintained a dead black and repainted at regular intervals.

(2) *Avoidance of Glare.*

The Committee recommend that no lamps should come within the solid angle subtended at the eye by the blackboard and a space two feet above it, unless they are completely screened from the eye by a shade impervious to light. In general it is desirable that no incandescent surface should be visible to the eyes of students or teachers while carrying on their ordinary work.

Another source of glare is the direct reflection of light from the polished surfaces of the desks or paper. It would be desirable for text-books intended for the use of young children to be printed on matt paper that is sensibly free from prejudicial reflection of this kind.

As a further means of avoiding this defect the Committee advocate the use of shades in which the brightness of the source is spread out over a considerable area, and the judicious use of reflection from the walls and ceilings of the room. These should be of such a texture that any considerable regular reflection is avoided, glazed and shining surfaces above the dado being specially objectionable.

(3) *Avoidance of Inconvenient Shadows.*

In the class-room the lights should be so arranged that inconvenient shadows cast by the body on the desk should be as far as possible avoided. The precautions suggested under the previous heading, and particularly the use of light-tinted surroundings, which serve to diffuse the light, may be recommended with a view to softening the shadow. The ceilings should be preferably of a warm white colour, and the walls and all woodwork above the dado should be light in tint.

A vast scheme of medical inspection of school children has recently been adopted in this country, and it is surely desirable

that this should be reinforced by inspection of the lighting conditions. Much is doubtless being done to mitigate defective eyesight by the provision of suitable glasses, etc., but it is of prime importance to make sure of the removal of the causes of the evil.

The above recommendations, while intended mainly for schools, would also apply to the lighting of colleges and evening

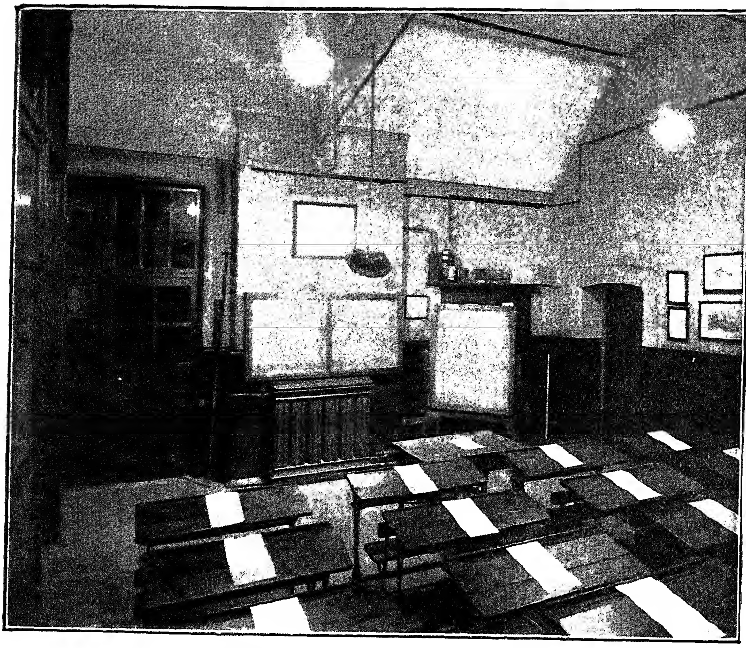


FIG. 154.—An interesting gas installation in a class-room, consisting of four semi-indirect units for general lighting and local lighting for the blackboard.

institutions — perhaps with the greater force because these institutions make more use of artificial light. The illumination of a lecture-theatre is naturally a somewhat different problem from a class-room. For example, there is more scope for special illumination on the blackboard and demonstration table, where experiments are shown to the students. A good scheme of this kind, in use at the Crawford Institute at Cork, was recently described in the *Illuminating Engineer* by Mr C. E. Greenslade.[1] The general illumination was provided by incandescent lamps in prismatic reflectors placed near the ceiling, and the local lamps

[1] *Illum. Eng.*, London, vol. vi., 1913, p. 417.

for blackboard and demonstration table were equipped with opaque metal ones. In fig. 154 we show a gas-lighted class-room where a somewhat similar method has been used.

In the "nine-point" plan recommended for a somewhat larger size of room (28 feet by 28 feet by 14 feet) by the Boston Commission in 1907, 40-watt electric lamps in prismatic glass shades, hung at a height of 10 feet 6 inches, were used. The

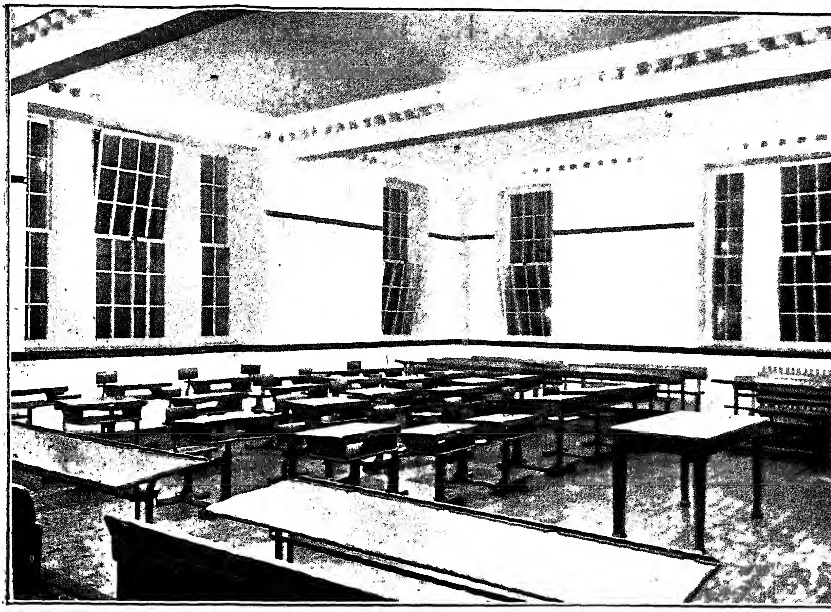


FIG. 155.—A class-room at the Leeds Training College lighted generally by tungsten lamps and Holophane reflectors.

(3·5 foot-candles on desks provided.)

consumption was slightly under 0·5 watt per square foot, and the illumination is stated to have been 2·5 foot-candles and very even.

Fig. 155 shows a class-room at the City of Leeds Training College, where very similar methods are used, the illumination in this case being about 3·5 foot-candles.[1]

There are also many special problems involved in the lighting of laboratories, workshops, and rooms devoted to various arts and crafts. Some such installations were described in the discussion before the Illuminating Engineering Society. Useful

[1] *Illum. Eng.*, London, Jan. 1913, p. 11.

data may also be derived from the account of the lighting of the Leeds Training College (*loc. cit.*).

Enough has been said to show the importance of illumination from the standpoint of the educationalist. It may, indeed, be said that light plays a much more important part in education than ever before. Printed records have replaced oral tradition. Demonstrations, diagrams, and lantern slides now form an essential accompaniment to any lecture, and even the cinematograph is being pressed into the service of education.

To-day we tend more and more to impart instruction through the *eye* instead of through the *ear*.

Library Lighting.

Library lighting has much in common with the lighting of schools, and the subject has been dealt with by the Illuminating Engineering Society of London in a very similar manner. In 1911 papers on this subject were read by Mr S. L. Jast (Chief Librarian of the Croydon Public Libraries), Mr J. Duff Brown (Borough Librarian, Islington), and Mr J. Darch,[1] and, in the discussion that followed, the results of a series of tests in London libraries were given by the authors. The whole discussion was reprinted and distributed among members of the Library Association, and subsequently a Joint Committee of the Illuminating Engineering Society and the Library Association was formed to discuss the subject in greater detail.

A preliminary report was issued by this Committee in 1913.[2] The chief recommendations embodied therein were:—

> A minimum illumination on the desk or table of 2 foot-candles for ordinary reading, a higher value (5 foot-candles is suggested) being recommended in the case of books in fine type and old manuscripts made of material with a low reflecting power. A minimum vertical illumination on book shelves of ½ foot-candle. A general illumination of not less than ½ foot-candle, measured in a plane 3 feet 3 inches above the floor.

As in the case of school lighting, general recommendations are made regarding the avoidance of glare, inconvenient reflection from shiny surfaces, and avoidance of unduly sharp shadows.

It is expected that more detailed recommendations will be added in a future report. Readers may also be referred to a

[1] *Illum. Eng.*, London, vol. iv., 1911, 83–107, 142–152.

[2] *Ibid.*, vol. vi., 1913, p. 366.

very full account of the lighting of the Carnegie libraries in New York, by Mr L. B. Marks.[1]

In lighting a library the first point to be considered (and there is much discussion on this point) is the choice between general and local lighting. Opinions are divided as to which works out the cheaper in practice, and the results seem to depend on the nature of the library. Local lamps for each reader can be turned on and off as required, and are in this sense economical as compared with the condition of lighting the whole room for the benefit of a few readers. But if all the seats are continually occupied, there is not much gain in this respect, and the cost of maintenance will probably be higher. Moreover, a certain amount of general illumination will be required in any case in order to light up the surroundings. One advantage of uniform general lighting, from the librarian's standpoint, is that the furniture can be readily rearranged without affecting the lights—a matter that is not so easily settled when each table has its local lamps wired to it.

From the reader's standpoint a distinction should be drawn between the requirements in different classes of libraries. In most public libraries there are rooms set apart for specific purposes. For example, there will probably be a lending library a general reading-room where papers and periodicals are kept, and a reference library where more serious reading is undertaken by students. The reading-room is open to the general public, but a permit may be necessary to gain access to the reference library.

In the *reading-room* general lighting is almost invariably provided. This room, being devoted to light literature, is usually more or less crowded, so that a good reading illumination is needed all over the room. People drop in for recreation, and appreciate a brightly lighted room. The walls and ceilings are usually light in tint, and this assists the illumination. Occasionally special shaded lamps are provided over the newspaper stands. In this case special care is necessary to avoid "shiny reflection" from the paper. It is by no means easy to secure even illumination over a slanting sheet of newspaper by means of a local light; if, in order to avoid shiny reflection into the eyes, the lamp is arranged so that the rays strike the paper somewhat obliquely, small irregularities in the paper (impression of type, folds, and crumples)

[1] *Trans. Illum. Eng. Soc. U.S.A.*, vol. ii., Oct. 1908.

are apt to become evident. For this reason such racks are probably best illuminated by general illumination. In this case there is another defect—shadows thrown by the hand and shoulders of the reader—to be guarded against. It may be suggested that for this type of room a general illumination of about 3 foot-candles, provided by semi-indirect lighting, would be the best solution. This is an effective means of avoiding inconvenient head shadows, and is well adapted to the illumination of sloping surfaces. It would require light walls and ceilings, but, as has been mentioned, these are the rules in general reading-rooms. A few judiciously spaced semi-indirect fittings would also have a more graceful effect.

In a *reference or student's library* the requirements are somewhat different. Readers here are doing more serious work. They prefer local well-shaded lamps and comparatively subdued surroundings—conditions which are usually considered favourable to mental concentration. We find a tacit recognition of this in the fact that the reference libraries are usually decorated in a darker style than the general reading-room.

Local lamps, supplemented by sufficient general illumination to enable people to see their way about and to read the titles of books on shelves, therefore seem to be the most approved method of lighting. This method is followed in the famous British Museum reading-room. The table lamps should be so shaded that the reader's eye cannot see the filament or mantle, and the shade should either be opaque or, if translucent, toned down to a very mild order of brightness. Opal shades with green exteriors are common, and answer well in this respect. But they are sometimes too shallow to cover the source completely, and are not usually shaped with a view to giving even illumination.

The general lighting should be sufficient to give ½ foot-candle both on the shelves and gangways. In reference-rooms the lights are not infrequently hung at a considerable height, so as to be out of the ordinary range of view of readers. It is therefore most essential that they should be screened with proper concentrating reflectors. Otherwise much of the light will strike the dark walls and ceilings and be lost, and comparatively little will be thrown downwards. A common defect in library lighting is for the chandeliers to be placed over the gangways. This method was formerly used in the London Patent Office Library, and until the local lamps were added over the central

tables the reading illumination was decidedly low. The right place for the chandeliers is above the tables, where the light is required. In this case proper reflectors can be fitted, throwing the light downwards and concealing the source from the eye.

A disadvantage of low-hanging chandeliers is that anyone attempting to read the titles of books on shelves is apt to find himself "in his own shadow." When a light ceiling is available, indirect or semi-indirect lighting would doubtless be a useful means of providing the general illumination, and would be particularly useful for giving the moderate illumination required on the shelves.

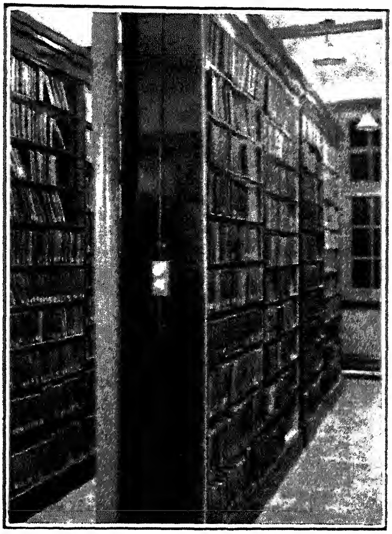


FIG. 156.—Rack lights by central tungsten lamps and Holophane reflectors (Enfield Public Library).

The problem of *shelf lighting* is a somewhat difficult one to the librarian. At the British Museum local shaded lamps can be very conveniently used, being attached some distance from the books, underneath the gallery. The arrangement permits of reasonably uniform illumination, and seems to answer well. In most cases the expense involved in local shelf lighting is an obstacle, and there is also a difficulty in getting reflectors of moderate price which will illuminate the shelf evenly from top to bottom. In the discussion before the Illuminating Engineering Society in 1911 the authors illustrated a number of conventional methods of lighting shelves by more or less unsuitable reflectors, and it was pointed out how very uneven the illumination in such cases is apt to be.

A feature in many libraries is the series of *small coves devoted to classified books*, opening out of the main reading-room. These are sometimes left unprovided with local lights and depend on the strong illumination received from the central chandeliers in the main hall. [A librarian to whom we once mentioned this matter confessed that the practice was deliberate. He preferred that the people should *not* read in the coves, but in the main hall,

where they were under his eye!] In general such coves can be conveniently lighted by a single central well-screened lamp; and the height of lamp and type of reflector can be so selected as to illuminate both the table and surrounding shelves.

In the *lending library* the illumination of the shelves is an important feature. As the latter are usually arranged one on either side of the gangway, a central lamp provided with a suitable reflector will often do all that is required. Fig. 156,

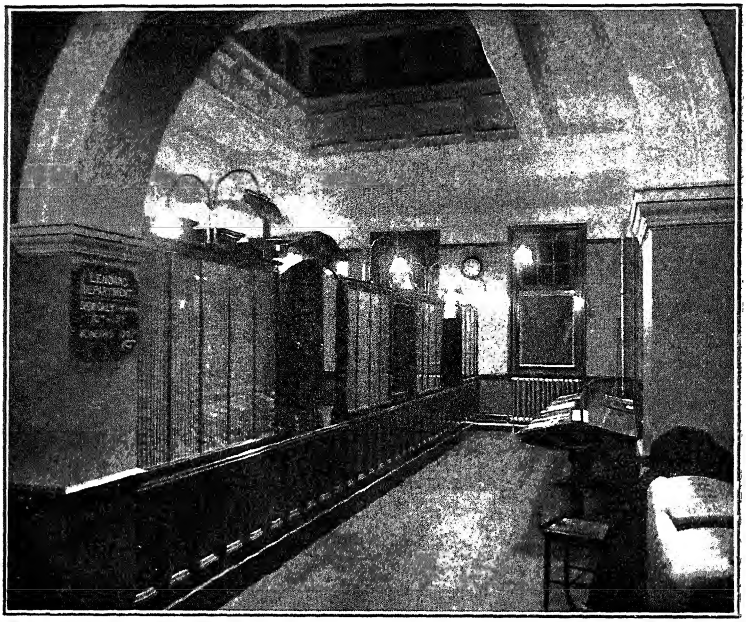


FIG. 157.—Enfield Lending Library, general illumination and local illumination of vertical registers by tungsten lamps and Holophane reflectors.

showing the arrangement at the Enfield Public Library, is typical.

It must be borne in mind that such shelves are sometimes examined chiefly by the librarians, who, by long experience, know exactly where every book is located and do not require very much light.

Apart from the shelves, the chief requirement is the provision of a good illumination on the counter where books are handed over. There are also sometimes vertical charts, indicating the books taken out, which demand special illumination. In fig. 157 will be seen one of them lighted by a Holophane Uniflux reflector.

Industrial Lighting.

The field of industrial lighting is so immense that it will only be possible for us to touch the fringe of the subject. Its importance may be gathered from the fact that a special book on the subject—one of the few works yet issued dealing with the special field of lighting—has just been issued.[1]

In our first chapter (pp. 24–26) it was pointed out how many recent congresses have dealt with the subject of industrial lighting, how the subject has received a steadily increasing amount of attention in the reports of H.M. Chief Inspector of Factories, and how ultimately a special commission has been appointed by the Home Office in this country to deal with the subject. These steps were detailed in a recent paper by one of the authors before the Royal Society of Arts.[2]

In the paper alluded to above, it was pointed out that good lighting has a claim (*a*) as a hygienic necessity, (*b*) as a means of preventing accidents, and (*c*) as desirable on purely economic grounds.

Good Illumination a Hygienic Necessity.—We find a general recognition that access of daylight in a factory is of vital importance. The legislation of Holland actually forbids the employment of children in rooms lighted only by artificial means and in the various reports of H.M. Chief Inspector of Factories constant reference is made to its necessity in places where poisonous trades are carried on or tuberculosis is apt to be acquired. The access of sunlight is of value in two ways. It destroys lurking bacteria, and, by encouraging cleanliness, lessens the risk of their existence.

That the provision of abundant illumination, natural and artificial, has a vital effect on the health, spirits, and self-respect of workers can scarcely be doubted. Men work more willingly in a well-lighted room than in gloomy surroundings, and take more pride in their personal appearance. Lack of attention to personal cleanliness is not infrequently the result of insufficient light.

There are also many trades (such as printing, engraving, needlework, and the textile industries) where a considerable demand is made upon the eye, and the result of continuous work by insufficient illumination may be highly prejudicial.

[1] *Factory Lighting*, by C. E. Clewell, 1913.

[2] "Economic and Hygienic Value of Good Illumination," by Leon Gaster, *Jour. of Royal Soc. of Arts*, London, 7th Feb. 1913.

And — as was pointed out in the case of school lighting —it is not only the direct deterioration of vision that is to be feared. Anything that puts a strain on vision affects the whole nervous system. People who are doing their work in constant difficulty will suffer sooner or later, and the rush and speed at which modern industry is carried on makes the effect of poor lighting felt very severely.

There are also possibilities of injury by exposure to excess of light. It is well known that precautions must be taken by men engaged in welding operations with the electric arc or oxy-acetylene flame. There are other industries, such as the manufacture of incandescent mantles and incandescent electric lamps, where the eyes of workers are constantly exposed to glowing surfaces; here, also, special precautions would seem desirable.

Poor Illumination as a Cause of Accidents.—Poor illumination is an important factor in the causation of industrial accidents.

In order to understand this we need only refer to the recent report of the Departmental Committee on Accidents in Factories, issued in 1911. Many instances are given of accidents occurring when men were unable to see clearly what they were doing. If a man is handling a rapidly moving cutting-tool, such as is commonly used in tailoring work, sawing-mills, etc., he needs not only sufficient illumination but well-directed light as well. An inconvenient shadow may cause him not only to spoil his work but to injure himself.

Good illumination is particularly important in places where dangerous machinery is used. Placing a guard round moving parts is not alone sufficient protection. The first essential in such cases is that the workmen should clearly see the outline of the dangerous machinery, and run no risk of tripping over unsuspected obstacles. Cases can be quoted of men at work at the docks who have slipped from scaffolding when they were working in the faint light of early morning, or who have been misled by a deep shadow when stepping on a somewhat precarious foothold. Other cases might be mentioned of men carrying molten metal who have stumbled and fallen while crossing ill-lighted passages, and of people tumbling down a flight of steps simply as the result of insufficient and badly arranged lights. Some interesting statistics on the subject of accidents in factories were recently presented by the Fidelity and Casualty Co. of New York, and are reproduced in figs. 158 and 158A. They show that accidents occur most frequently in

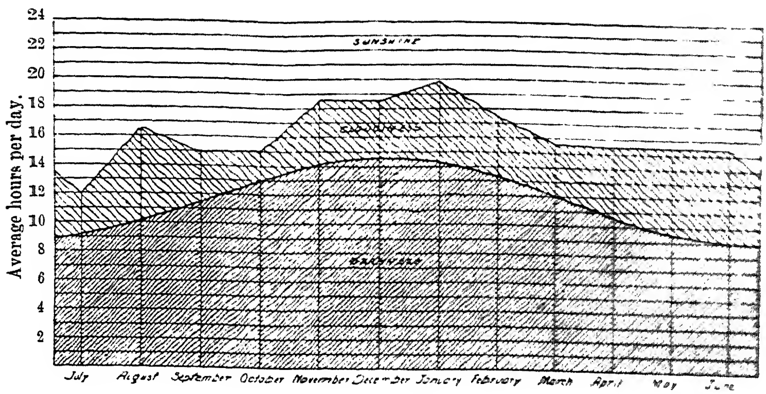


FIG. 158.—Chart showing average hours per day of sunshine, cloudiness, and darkness for each month during 1910 (New York City).

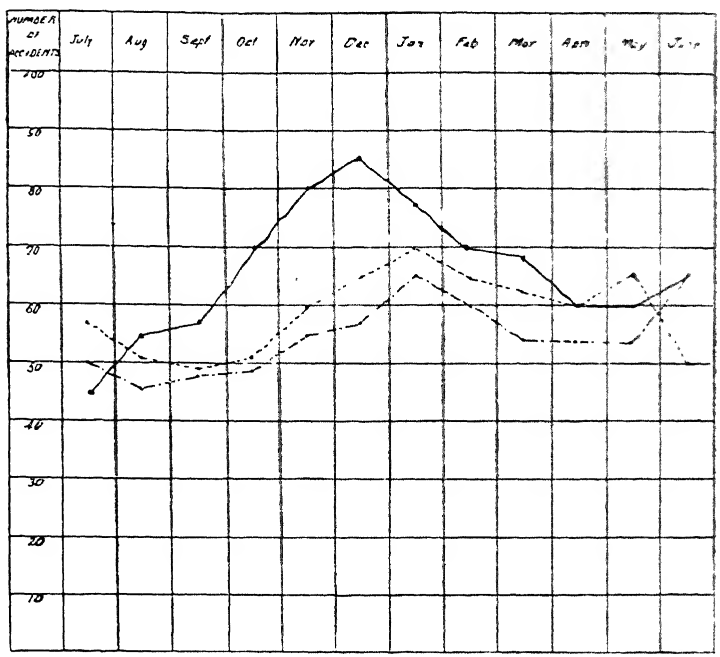


FIG. 158A.—Chart showing the seasonal distribution for three successive years of about 700 deaths annually from industrial accidents reported from an area embracing 80,000 plants.

(Note similarity of curves in these figs.)

the short days of winter, when artificial light is mainly used, and it is stated that the time of the day when accidents and spoiled work are most frequent is the period when artificial illumination is in use.

Accidents may also arise through neglect of plant and machinery. If the plant cannot be clearly seen, it is not kept clean as it should be, and dirt is one of the worst diseases it can suffer from, paving the way for the inevitable break-down.

Economic Aspects of Good Illumination.—Bad lighting, by causing accidents, also leads to economic loss.

Any employer of wide experience will admit that a break-down, either in his machinery or in the staff who work it, is always uneconomical; the moral effect of a bad accident to an employee is felt for some time afterwards, and leads to disorganisation of the factory. There are many industries in which a stoppage of machinery, even for a short time, throws the whole system out of gear.

Again, the same conditions that are responsible for accidents also lead to spoiled work. The writers have met cases in which the percentage of spoiled work decreased quite remarkably when the illumination was improved. Indeed, it is a common experience to find that when the light in one section of a factory is improved a clamour immediately arises among the work-people in other sections lighted on the old plan. For example, in a clothing factory, the girls, who were piece-workers, urged that it was unfair that some of them should be better treated in this respect than others! They fully recognised that improved illumination meant less work rejected and increased output. The employer has every reason to welcome good illumination, and has little to gain by grudging the small initial expense sometimes necessary to put things on a proper footing. What is the use of installing expensive machinery, securing a highly-paid and skilled staff of workmen, and then grudging the relatively small cost of sufficient light to enable both to do their duties? A recent series of investigations in the United States has shown that in that country the cost of lighting was almost invariably but a trifling fraction of the total wages bill, in many cases less than 1 per cent. It has been estimated that the cost of lighting during an average working day is equivalent to the wages paid *for only six minutes' work* on the part of the occupants of the room.

A short time ago an inquiry was addressed by the National

Electric Lamp Association to a large number of industrial concerns in the United States. Out of 209 replies, 164 mentioned that improvements had been recently made in their lighting, and a number of expressions of opinion were received to the effect that increased production, better-class goods, and greater satisfaction on the part of the workers had been the result. Summarising these 164 cases, it was found that 28 per cent. said that the lighting costs had been reduced; 19 per cent. said that their output was increased; 37 per cent. said that the workers were better satisfied; 13 per cent. said the change was too recent to give figures; 64 per cent. said in general terms that they were satisfied that the change was well worth its cost, and less than 5 per cent. said that they had traced no direct benefit as yet.

This example suggests that a general inquiry into the experience of manufacturers who have recently improved their lighting would show that they had gained as a result. The chief difficulty, as a rule, is to induce manufacturers to make the change. Once better lighting is introduced its benefit is recognised. There seems to be an opening for methods of studying and recording the resulting improvement in quality and output.

Mr R. Thurston Kent[1] has devised a method of timing accurately the various operations in a factory by the old and new lighting conditions. By this means it might be possible to trace exactly where the gain occurs and which processes are susceptible to improvement under better light.

Unfortunately, it is not always easy for the ordinary engineer to get data of this kind. Manufacturers, having secured a good thing, are naturally averse from publishing broadcast their experience and putting it at the disposal of their competitors.

Let us now turn to a few of the practical points to be observed in factory lighting. Some of these have been clearly brought out in the tests recently carried out by Mr D. R. Wilson, in cotton mills, printing-offices, and foundries,[2] to which reference has already been made. Some very practical information is given in Mr Clewell's book on the subject, and there have been from time to time papers before the Illuminating Engineering Societies and in contributions to

[1] *Illum. Eng.*, London, vol. v., 1912, p. 423.

[2] See Reports of H.M. Chief Inspector of Factories for 1911 and 1912.

the technical press dealing with the lighting of various kinds of works.[1]

The Illumination required in Factories.—In considering the illumination required in factories, Mr Wilson draws a distinction between "inspective" and "detective" work, according as the work entails continuous application of the eye to one small point or area, or consists merely in keeping a general watch over a given process, actual labour being demanded only when a fault occurs. A value might readily be specified for the minimum general illumination requisite to enable people to see their way about in comfort and to distinguish surrounding objects clearly. Mr Wilson, for example, suggests that a foundry might be considered adequately lighted if the illumination on the floor were 0·5 foot-candle, and the same figure might suffice for many yards, packing-rooms, etc., where large objects are handled and the work does not impose any great tax on the eyes.

This general illumination should always be available. But, in addition, a specific extra illumination would usually have to be provided according to the nature of the work. It must be confessed that we have as yet insufficient data on which to base our estimate of what is really needful for many of the varied processes that go on in modern factories. It is true that tables are published from time to time containing information on the subject; but these figures merely refer to general practice, and are not, as a rule, the result of an exhaustive search after the ideal.

Mr Wilson's tests show that the illumination provided in textile mills for one and the same process varied to an extraordinary degree, and the papers before the Illuminating Engineering Society by Messrs Goodenough and Eck show that an equally striking diversity exists in printing-offices. For example,

[1] See, for example—"The Lighting of Printing Works by Gas," by F. W. Goodenough (*Illum. Eng.*, London, vol. v., 1912, p. 171); "The Lighting of Printing Works by Electricity," by J. Eck (*Illum. Eng.*, London, vol. v. p. 185); "Mill Lighting," by G. H. Stickney (*Trans. Am. Illum. Eng. Soc.*, vol. vi., 1911, p. 478); "Localised and General Illumination," by G. H. Stickney (*Am. Machinist*, 2nd Nov. 1911); "Factory Lighting," by L. B. Marks (*Trans. Am. Illum. Eng. Soc.*, vol. v., 1909, p. 805); "Industrial Lighting," by K. Eshleman (*Proc. Am. Inst. of Elec. Engs.*, Jan. 1913); "Industrial Lighting," by C. E. Clewell (*Proc. Am. Inst. of Elec. Engs.*, July 1912); "Lighting of Textile Mills," by J. Calder (*Elec. World*, 22nd Jan. 1913); "Lighting of an Automobile Works," by H. H. Magdsick (*Elec. World*, 6th April 1912).

FIG. 159.—Bad local lighting.

The lamp is incompletely covered by the reflector and shines in the eyes of the workman instead of illuminating the work.

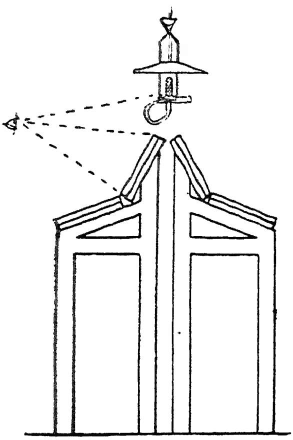
FIG. 159 A.—Good local lighting.

The reflector completely screens the lamp from the eyes and concentrates the light on the work, where it is chiefly needed.

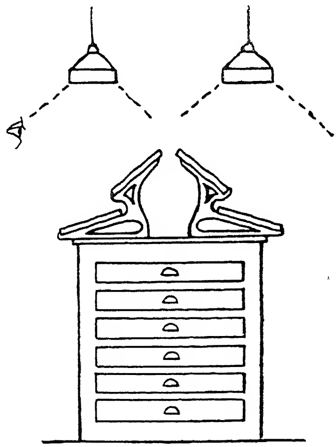
in the case of six different printing-works, values of illumination range from 3·4 to 26·8 foot-candles. Mr Wilson gives the following figures for printing and cotton factories:—

	Illumination (foot-candles).
Clothing (machine) room	2–36
Handkerchiefs	2–8
Composing-rooms	3–30
Cotton weaving	1–5
Linen weaving	3–18

In cotton spinning- and preparing-rooms much lower values, ranging from 0·1 to 6 foot-candles, were encountered.



Imperfectly shaded lighting of compositors' frames by upright incandescent gas. The incandescent mantle is fully exposed to the eye, and the angle of glare is 46° at the lower and 16° at the upper edge of the upper case. The shadow of the compositor also is thrown on the frame by a similar unshaded source behind him.



Good method of lighting compositors' frames by electric glow-lamps. The eye is protected from the source by the cylindrical attachments to the conical shades. The general effect of the lighting is very restful, owing to the absence of glare and of light in the top part of the room.

FIG. 160.—Comparison of good and bad methods of lighting compositors' frames. (Report of H.M. Chief Inspector of Factories, 1911.)

It should surely be possible to form an approximate estimate of the illumination needed for a well-defined process such as printing and weaving; if these variations exist, there must be many cases in which the illumination is either deficient or excessive.

Avoidance of Glare, Moving Shadows, etc.—It is hardly necessary to insist once more on the importance of avoiding glare and the use of suitable reflectors in factory lighting. Figs. 159 and 159A illustrate very clearly the great advantage of

using a suitable shade or reflector to screen the source from the eyes and concentrate the light on the work.

This point is very forcibly illustrated in the lighting of compositors' frames. In works lighted on the old-fashioned plan, with lamps imperfectly screened with shallow reflectors, one not infre-

FIG. 161.—Showing illumination of composing-frames at a large printing-works by gas.

The incandescent mantles are completely screened by opaque reflectors and an even illumination provided on the working surface.

quently finds that the workman has contrived for himself a paper screen to keep the light out of his eyes. The two diagrams in fig. 160, reproduced from Mr Wilson's report, indicate the essential advantage of a well-shaded lamp; and in figs. 161 and 162 we reproduce two general views of printing-works lighted respectively by gas and electricity, in which good modern methods are used: fig. 163 shows the use of semi-indirect arc lighting, which is also employed in the machine-rooms of some leading newspapers.

The choice of a reflector for factory lighting needs some care. Besides the usual functions of screening and directing the light, it is expected that it should collect as little dust as possible, and that it should be easy to keep clean. According to Clewell's tests, the deterioration in illumination caused by a three weeks' deposit of dust and dirt on glass reflectors in offices may be about 10 to 15 per cent.; but the corresponding loss in an average *factory* in the same time might amount to 40 to 50 per

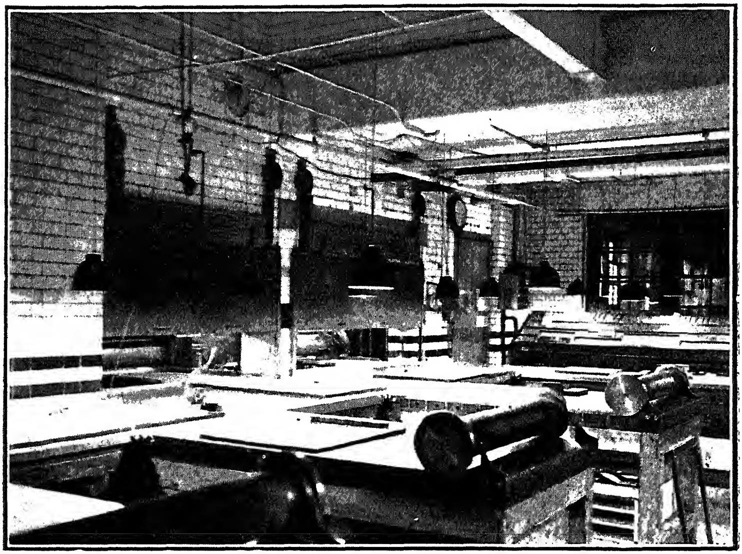


FIG. 162.—Lighting of a lay-off table in a printing-works by tungsten lamps in steel reflectors (Benjamin), concealing filaments from the eye and distributing light on the table.

cent. In most large factories it is well worth while to keep a staff at work keeping the lamps and shades clean, and Clewell makes some suggestions as to how this work might be standardised. In the case of incandescent gas-burners the importance of maintenance is even more essential, as most burners tend to suck in a certain amount of dust and in time become choked up. In this respect the high-pressure system is at a certain advantage, since the pressure keeps the passage clear. It has also been suggested that systems compressing a mixture of gas and air are advantageous in such circumstances, as the air for combustion can be taken in outside the room, where it is comparatively free from dust or fluff.

Another defect that is very objectionable in factories is a flickering light. This may arise through unsteadiness in the source itself (arc lamps with poor quality carbons are notorious sinners in this respect), or may be due to the shadows of moving belts and machinery. The best method of guarding against this last form of flicker is *good diffusion* of light; and by judicious grouping of the lamps in a whitewashed room, or by the use of indirect illumination, incorrect moving shadows can usually be

FIG. 163.—Semi-indirect (Union) arc lighting in the paper room of a printing-works.

avoided. A flicker is sometimes produced by the vibration of lamps, but this is usually when the illumination is streaky: with a uniform illumination, free from striations, it should not occur. In factories the arrangement of lamps is often determined by considerations such as do not usually affect ordinary interior lighting. For example, by the position of large girders and iron lattice-work, travelling cranes, etc.; and "over-all lengths" of the lamp is frequently an important item.

In machine-shops a large central space, leading into a number of side bays, is a very usual arrangement. The lighting of such a shop by gas, oil, and electricity respectively was recently

treated in three papers by Franklin Thorp, Hadyn T. Harrison, and J. E. Evered.[1] The central area, given up to heavy work and requiring a good general illumination, is usually lighted by powerful flame arcs, or incandescent gas lamps (high pressure); the adjacent bays by appropriately spaced smaller incandescent units. A method that has a decided advantage, where the circumstances permit it to be used, is the placing of lamps in ceiling recesses or between the girders, so as to be screened from

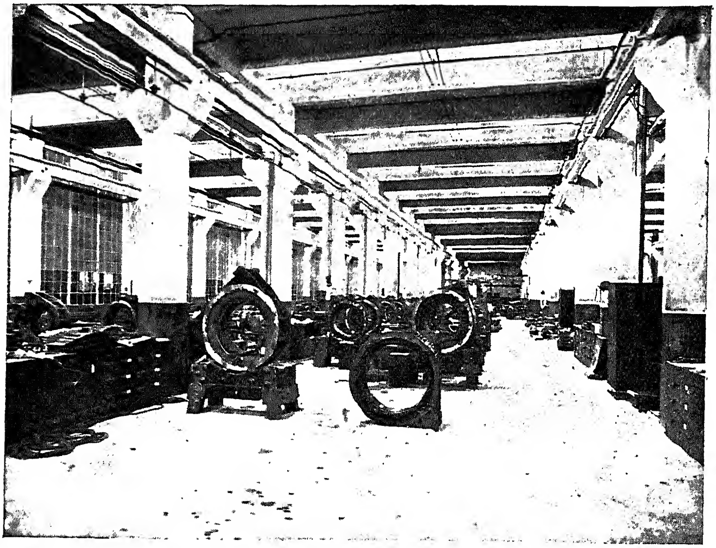


FIG. 164.—General illumination of machine-shop.
The installation consists of high candle-power (Mazda) electric lamps, equipped with Mazdalux reflectors hidden in the ceiling bays, so as to be kept well out of the line of vision.

the eye. This method (illustrated in fig. 164) answers best when a white ceiling is available. For lathes, where more or less fine work is undertaken, local light by well-screened lamps is usually desirable. On the other hand, where big work is done—*e.g.* rolling-mills, foundries, etc.—the lighting almost always is done on the "general principle."

The lighting of rooms containing closely packed and intricate machinery, such as printing-machines, cotton-looms, etc., requires somewhat different treatment. There seems little doubt that in such cases the diffusion of light from large bright surfaces, so as to penetrate into all the corners and amidst the mechanism,

[1] Papers read before the Manchester Association of Engineers, 25th Jan. 1913, *Illum. Eng.*, London, vol. vi., 1913, p. 99.

is the most important factor. For this reason the use of whitewashed walls and ceiling is a valuable aid to the lighting engineer, and the use of indirect and semi-indirect methods would often be beneficial. Sometimes the irregular nature of the ceiling is a difficulty, and in some mills in the north of England the manufacturers have gone to the expense of coating them over with enamelled sheets in order to get a good

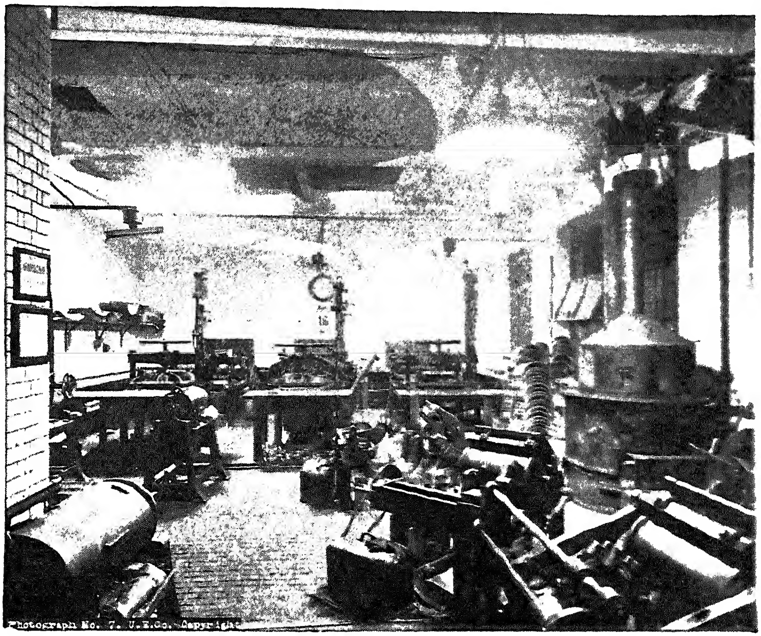


FIG. 165.—Indirect arc lighting (Union) in a foundry.
The type of unit shown is conveniently used when a white ceiling is not available.

reflecting surface. In some printing-works reliance is placed on hand-lamps when it is desired to explore underneath the machines; but in any case well-diffused general illumination is essential.

In spinning-works the machines are commonly arranged in alleys, with a gangway between, the windows being located at the end of each gangway so as to allow the light to enter unobstructed. The artificial light is usually provided by rows of lamps hung from the ceiling at intervals, in the gangway, so as to illuminate the machines on either side. Sometimes a separate light is allotted to each machine. This is possibly a better

arrangement, but such lights should be well shaded and should be supplementary to general illumination.

There are many cases in which the choice of local or general illumination is optional. For example, one meets many composing-rooms in printing-works where general lighting is used and is considered satisfactory. But on the whole the compositor seems to prefer a local light, preferably adjustable. The view taken as to the amount of light required seems to vary with the individual, and is perhaps to some extent a function of age.

FIG. 166.—Example of central lighting of spinning-room alleyway. (Tungsten lamps in enamelled (Mazdalux) reflectors.)

The local light, as explained above, should be fully screened from the eye. There is one objection to local lighting, namely, that such lights, while giving a good illumination on the frame, are apt to leave the drawers in dense shadow. For this reason a certain amount of general lighting is also desirable. Perhaps the ideal solution would be a combination of local lamps and general semi-indirect illumination.

As a general rule, one finds that local lighting is essential for all purposes where concentration of mind is needed, and the work is exceptionally trying to the eyes. In the tailoring trade, for example, where much work on dark material is done, a very high illumination is required, and it is hardly possible to provide for the needs of the worker without local lights.

A curious confirmation of this point was mentioned in a report on trades affecting the eyes, presented to the Royal Society of Arts in 1855 by Mr White Cooper, surgeon to St Mary's Hospital. He stated that the number of cases of eye-strain among workers in these trades increased considerably during periods of national mourning. This was ascribed to the change of work to dark stuff, carried through as a rule at short notice at considerable pressure, and involving extra work by artificial light.

In what has been said above we have mainly used as illustrations problems involved in the lighting of machine-shops, and printing- and textile-works. But in every branch of factory lighting these same general problems occur. There are, in addition, special circumstances depending on the nature of the business of which the lighting engineer must take account. For example, in many chemical works the corroding effect of fumes on joints, wires, and insulation must be guarded against. In other branches of work, *e.g.* in illumination for processes using rapidly moving cutting-edges, the *direction* from which the light comes is vital. Again (as explained in Chapter VI.), in sections of the textile and printing trades, drapery, and many other trades, the question of the colour of the illuminant is of great importance. The truth is that the lighting engineer, in order to make a success of his work, must not only understand illuminating engineering, but must make a study of the particular needs of the trade with which he is dealing.

The Lighting of Halls, Concert Rooms, Theatres.

The lighting of a large hall has a good deal in common with the illumination of a lecture-theatre. It is necessary to provide a moderate illumination over the body of the hall, and to add special local lighting from the platform. The light should be sufficient, and the eyes of the audience should not be troubled by glare.

In most public halls the general illumination provided throughout the auditorium does not exceed 1 foot-candle, and this is doubtless enough to enable the programme to be read; but perhaps 2 foot-candles might be considered better still. The most usual method of lighting is to use large candle-power lamps, equipped with suitable reflectors, and spaced to give even illumination over the auditorium. Sometimes the lamps are

mounted on a few large chandeliers. There are people who believe that in the course of the next few years the use of large chandeliers will gradually cease, and the lights, instead of being spaced at intervals over metal work, will be collected together in large hoods, bowls, etc. The method seems a more promising one from the lighting standpoint, and should lend itself well to artistic treatment. Whatever method is adopted, the lamps should be well shaded, and should preferably be placed high up out of the direct range of vision of the audience. Fig. 167, showing the main hall in the Leeds Training College, illustrates the advantage of placing these units high up. In this case the hall is lighted by four Nonpareil sun-burner units, each equipped with twenty-eight inverted mantles.

The extra illumination on the platform is usually required by the speakers or performers. For example, it enables a lecturer to read his notes in comfort and to illuminate any objects he may wish to exhibit to the audience. Special lighting is, of course, necessary for an orchestra, and a local shaded lamp for each performer is now practically always provided. The illumination on the platform also serves the purpose of fixing the attention of the audience on this spot, in the same way as the brighter illumination of the stage holds all eyes in the theatre.

In theatres, cinematograph halls, etc., where the lights are turned down during the performance, the illumination in the auditorium is frequently allowed to fall very low. In cinematograph theatres it is becoming customary to dim the lights, but not to extinguish them altogether during the performance—a precaution that would no doubt lessen the risk of a panic in the event of a fire. It seems possible that a low general illumination of, say, 0·25 to 0·5 foot-candle would be of convenience to people at the theatre, and would not be sufficient to distract their attention from the performance. There are some theatres in London where it is extremely difficult to read a programme in the pit even when the lights are full on. In the theatre each member of the audience needs the same light; in a cinema hall, on the other hand, it is mainly at the back, where people are constantly entering, that the light is needed. It has therefore been recommended that the illumination should be graded from about 0·3 foot-candle in the front of the hall to 1 foot-candle at the back.

In theatres and cinemas, where the performance consists

FIG. 167.—Assembly hall lighted by four "Nonpareil" sun-burners, consuming roughly one-ninth of a cubic foot of gas per square foot of floor area, the illumination produced being 8 foot-candles.

essentially in an appeal to the eye, anything in the least glaring is out of place; and a soft subdued lighting for the auditorium is best. Bracket lights on the eye-level should be used with caution. If it is considered necessary to supplement the ceiling lighting in this way, concealed lamps designed to illuminate light-tinted panels, frescoes, etc., similar to those shown in the illustration of the West End Cinema (see p. 308), may be used with advantage. This method has considerable artistic possibilities. The use of an illuminated dome in the ceiling is also becoming common, and the nature of the building usually lends itself well to this treatment.

In the theatre the need for avoiding glare has long been recognised, and the motto "Light on the object, not in the eye" has been adopted from the very earliest days of stage lighting. But there is another form of glare, the shock experienced when the lights are suddenly turned up, against which the audience is not always protected. In cinemas, where the lights are turned on so much more frequently, the effect of this sudden shock is apt to be particularly trying. In the best modern theatres and cinemas the lights are switched on through a rheostat or "dimmer," and the change from light to darkness is made gradually.

The lighting of the stage is an art in itself. Something will be said regarding stage devices under the head of decorative lighting. Readers may be referred to an article in *The Illuminating Engineer* for 1908[1] and to a book on decorative electric lighting by Prof. W. Biscan of Leipsic. This work also contains a useful summary of the methods of providing for safety in theatres by alternative lighting arrangements.

The Lighting of Hospitals and Infirmaries.

Several papers have recently been presented dealing with hospital lighting. Most of those who have investigated the subject agree that the lighting of hospitals and infirmaries is in general very poorly done. Yet the claims of good illumination may be considered exceptionally pressing in the case of people in an enfeebled condition of health, by whom small irritations and inconveniences will be felt which would be of comparatively small consequence to a healthy subject.

[1] "The Development and Present State of Stage Illumination," *Illum. Eng.*, London, vol. i., 1908, p. 645.

The importance of abundant access of daylight into the wards is, of course, well realised, for in a hospital surely the hygienic cleansing action of the sun's rays are particularly valuable. It may be mentioned that a few years ago the Westminster Hospital obtained an injunction limiting the height of a neighbouring hall then in course of construction on the ground that it would obstruct the daylight and impede the recovery of patients.

The artificial lighting of a hospital may be divided roughly into two sections—the lighting of the wards, and the special appliances required for the illumination of the operating table. Particulars of the details of such appliances will be found in the papers referred to in the foot-note to this page.[1]

The chief essential in ward lighting is that there should be no glare, and that conditions likely to prove objectionable to the eyes of patients should be very carefully avoided. The illumination should be restful and subdued, and a value of 0·5 foot-candle has been suggested. Indirect methods have sometimes been recommended. On the other hand, some have contended that this method is undesirable, for the reason that the patients lying in bed and looking upwards would be troubled by the brightly illuminated ceiling; it has therefore been urged that local well-shaded lights are preferable. This objection might perhaps be met by using indirect units of relatively small candle-power and placing them above the gangway, so that the most brightly illuminated portion of the ceiling is that most remote from patients' eyes.

Objection has been taken to the method of placing lamps in concentrating reflectors above each bed, on the ground that the patient is not encouraged to read by artificial light in the hospital and does not require such a light, and that the glare is apt to be trying to the eyes of a patient lying on his back. On the other hand, such local lamps may be of assistance to the physician, providing a strong illumination under which to examine the patient while going his rounds. From this point of view the light above the bed would appear desirable, but it should only be turned on when required for this purpose; or, if the ward is electrically lighted, plugs may be provided from which current may be taken when desired.

[1] "The Artificial Lighting of Hospitals," by J. Darch (paper read at a Congress of the Royal Sanitary Institute at Belfast, July 1911; *Illum. Eng.*, London, vol. iv. p. 521). "Hospital Lighting," by W. S. Kilmer (paper read at the Convention of the Am. Illum. Eng. Soc., Sept. 1913).

Appliances for the illumination of the operating table usually involve the production of a high local illumination, up to 10 foot-candles or more, by means of lamps mounted in opaque concentrating reflectors. An elaborate system of mirrors (Siedentopf system) has also been used for the same purpose. In either case the intention is the same, to provide a very strong local illumination from a source which should be completely screened from the eye.

Church Lighting.

The lighting of churches demands tact as well as skill. There are usually many people connected with a church whose views have to be considered, and the limitations imposed on the lighting engineer vary widely according to the religious denomination of the church and the antiquity of the building.

There are certain broad rules, mentioned above in connection with the lighting of public halls, that should always be observed. Lights should be so placed that they do not dazzle the eyes of the congregation or the preacher. Nothing is more annoying than to have one's view obstructed by low-hanging chandeliers glittering with light, and such excessive intrinsic brilliancy is usually quite out of keeping with the nature of the building.

On the other hand, the intensity of illumination required differs somewhat according to the nature of the church. As a rule, congregations worshipping in modern buildings desire a good light. In most English churches a general illumination over the seats of 1 foot-candle would be suitable. But naturally it may not be feasible to light a vast cathedral in this way, and the nature of the worship may not require it. In most cathedral services the congregation do not take a very active part in the services, and therefore do not require a strong light. In the Greek and Russian Church, and in many Eastern mosques, most of the services are repeated by rote, and there is no need for the congregation to be able to read. Moreover, in many of these old churches subdued lighting and a certain air of mystery are traditional, and the introduction of modern illuminants and strong lights would not be welcome. When the Bevis Marks Synagogue in London was redecorated a few years ago it was decided to retain the original arrangements, which are modelled on the famous synagogue at Amsterdam, and to keep candles as the sole illuminant.

In the famous church of Santa Sophia in Constantinople the lighting is carried out by numbers of small oil lamps

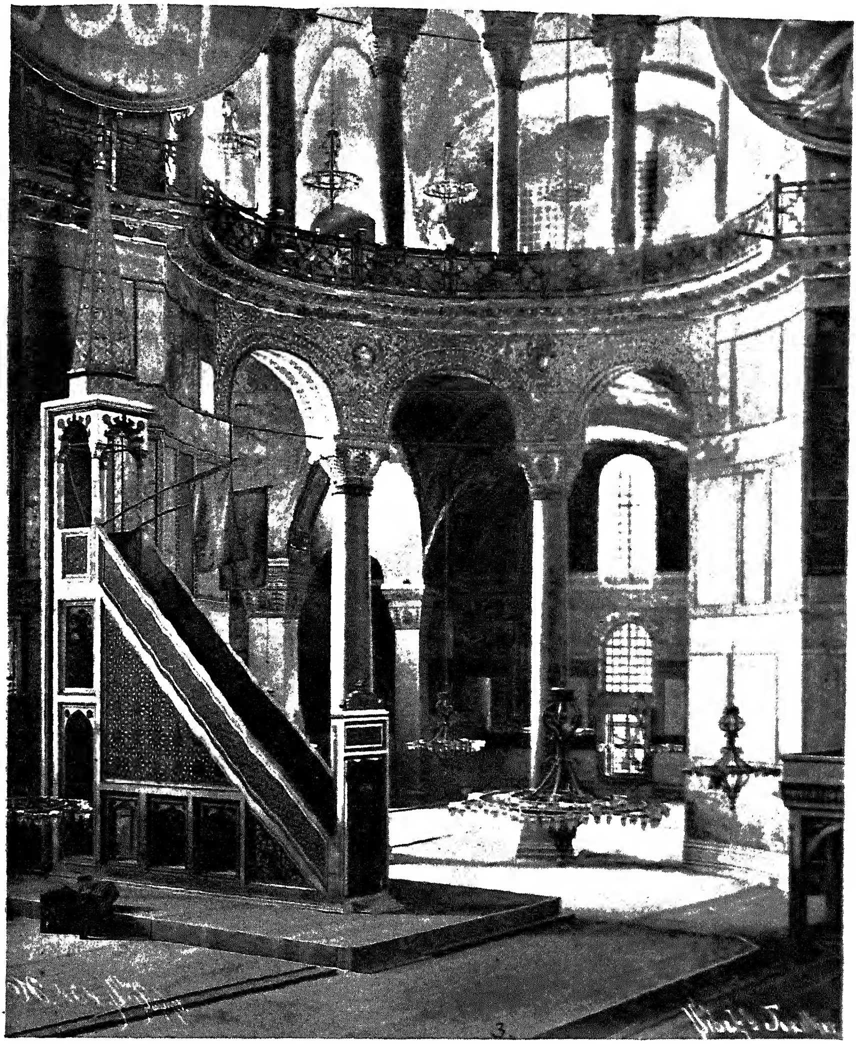


FIG. 168.—The famous mosque of Santa Sophia, Constantinople, lighted by numbers of small oil lamps on large chandeliers.

View looking from nave towards exedræ.

mounted on immense chandeliers; the effect of these myriads of little lights twinkling in the dusk is said to be very fine.

Nevertheless the new illuminants are making headway, and quite a number of old churches are now lighted by gas or electricity. Some of the vast suspended coronæ in Continental cathedrals are thus lighted. It would usually be preferable to get the additional light without its being obvious that modern lamps have been installed; for this reason, it may be suggested that the use of bare lamps or mantles should be avoided, and that they should preferably be screened in antique lanterns, etc., fitted with diffusing glass.

FIG. 169.—In this installation the illumination was improved by the introduction of a number of new fittings, all following the original Moorish design.

Holophane hemispheres and pines were used to screen the electric lights, and the text in the background was lighted by concealed lamps behind the arch.

There is room for considerable artistic skill in the design of fixtures to give additional light but to harmonise with the style of the interior. Fig. 169 shows a view of a synagogue, the lighting of which was recently remodelled under the supervision of one of the authors. In this case a number of additional fittings in Moorish style were designed, to harmonise with the existing installation, and were combined with Holophane glass pines and hemispheres. The installation is interesting as an instance of the compromise between the claims of improved illumination and faithfulness to the original style of the building.

In the case of buildings of national and historic importance—such as Westminster Abbey, St Paul's Cathedral, and other great cathedrals in this country—the lighting should surely be schemed

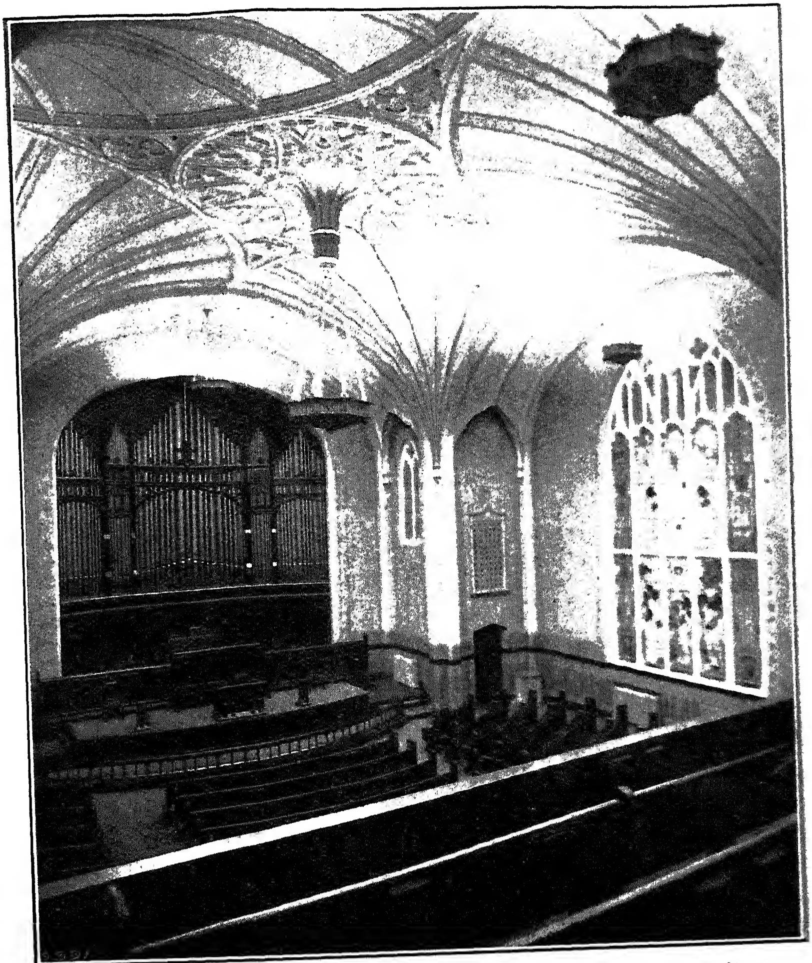


FIG. 170.—A view of the Eberhardt Memorial Church, Mishawaka, Indiana, U.S.A., lighted by indirect X-ray fittings.

out very carefully and special pains taken to avoid the introduction of incongruities.

It is impossibile to lay down any general rule for the lighting of churches. The most general method of lighting is by chandeliers, coronæ, etc., or by individual lights suspended from

the roof: lamps may also be mounted round the front of the gallery. Occasionally lamps are attached to the pillars, but in this case they are apt to be on a somewhat low level, and careful shading is essential.

In most churches some degree of local lighting will be needed. Special attention should be paid to the needs of the choir, and the pulpit or reading-desk require well-shaded local lighting. These lights need particularly careful screening, so that they neither shine into the eyes of the preacher nor dazzle the congregation. Readers may be referred to a special section on church lighting which appeared in the *Illuminating Engineer* some years ago, as well as to various articles and papers that have appeared from time to time in the American journals.[1] There are in the United States many handsome modern churches into which indirect electric lighting has been introduced. A case in point is the Eberhardt Memorial Church of Mishawaka (Ind.), sent us by the National X-Ray Co. of Chicago, and shown in fig. 170. The method would not be applicable in many of our older churches, but for new buildings it seems to have great possibilities. The imposing effect of the large units and the restful and subdued light seem well adapted to church lighting.

Illumination of Picture-Galleries, Museums, etc.

The artificial lighting of picture-galleries and museums has been very little studied at present. It seems to be assumed that such institutions will be mainly visited during the daytime. In some instances—in picture-galleries especially—artificial lighting is not introduced on the ground of safety. The treasures they contain are so priceless that even a remote risk of fire would not be tolerated.

On the other hand, it may be urged that the number of people who can spend much time in picture-galleries and museums during the daytime is strictly limited, that national treasures should be open to all, and that it should not now be out of the bounds of possibility to devise a method of lighting that is absolutely safe.

It will at least be conceded that if artificial illumination is

[1] See *Illum. Eng.*, London, Jan. 1910; also "Church Lighting," by R. B. Ely, paper read at the Convention of the Am. Illuminating Engineering Society at Pittsburgh, Sept. 1913.

introduced into picture-galleries and museums at all, it should be well done. It is of little avail to spend large sums of money on objects that appeal to the eye and then to grudge the relatively small expense needed to make them visible. It is well worth while to spend pains on a method of lighting that brings out all the points of interest in an exhibit. This is a case in which the motto "Light on the object, not in the eye" is particularly applicable. Glaring or badly placed lights, such as dazzle the eyes and throw inconvenient shadows, should at all costs be avoided.

In lighting a museum the method adopted should naturally depend on the quality of the exhibit. In a room containing fairly large objects good general illumination is desirable, and the light should be particularly well diffused so as to get into all the crannies and recesses. In such rooms indirect lighting would often be of service, especially if the architectural features and lighting were planned simultaneously. In the South Kensington Museum, built a few years ago, little was done in this respect. In the case of new buildings it is surely not too much to hope that the opportunities for such co-operation will not be lost.

It is by no means unusual to find all the rooms in a museum lighted on a uniform plan by chandeliers hung over the gangways, and comparatively distant from the objects they are meant to illuminate. If, in addition, the chandeliers are provided with shades which do not cover the filaments and have little directing power, the illumination of exhibits in the more remote parts of the room may be far from sufficient; and this effect of gloom and obscurity is intensified by the glare of the lights.

In rooms containing cases of small objects the special illumination of these exhibits by concealed local lighting is well worth attention. People are often attracted by a cabinet so lighted, who would otherwise pass it by. In some sections of the British Museum there are a number of cases illuminated in this way. On the other hand, it must be remembered that the contents of such cases are occasionally so valuable that it would not be permissible to introduce lights inside; also it is frequently the rule that only the curator should have access to the inside, and the case cannot be opened by any attendant for the purpose of installing new lamps, etc.

The artificial lighting of picture-galleries is a different and in some respects a simpler problem. In the case of most other

lighting installations we are chiefly concerned in obtaining a strong horizontal illumination, and the amount of light allotted to the walls may be relatively small. But in a picture-gallery these conditions are exactly the reverse. The illumination is mainly required on the walls where the pictures are hung, and the general lighting of the floor need not be powerful.

Some care is needed to ensure that the lighting appliances do not obstruct the view of the pictures; chandeliers, unless hung exceptionally high, are apt to have this effect. Some of the very large chandeliers met with in old palaces and mansions would certainly never be installed now. Other points that require attention are the avoidance of reflections of lamps in the glass of pictures, and the placing of lights in such a way that the view of a person drawing near to the picture is not obstructed by his own shadow. As a means of avoiding these defects, and in order to provide even illumination over a large area covered by pictures, indirect and semi-indirect methods would seem to have advantages. There are, however, many cases in which they cannot be applied, as the ceiling area is given up to skylights.

When we have to deal with isolated pictures, the use of special local lamps in appropriate reflectors of the type described in the last chapter (*e.g.* the Uniflux) may be preferable. This enables each picture to be treated separately. A carefully designed system is necessary to get even illumination over a large area, and to avoid direct reflection of this source. In some cases it may not be desirable to illuminate the picture evenly all over: for example, in a portrait the intention of the artist may be carried out best by concentrating the light on the face and allowing the illumination to diminish somewhat on either side of this point.

The daylight illumination of galleries is naturally best provided for by overhead lights. In one gallery in the United States artificial lighting on a similar principle has been provided, the lamps, in concentrating reflectors, being mounted above the skylight, which is made of diffusing glass. In this way an effect is secured somewhat similar to that of sunlight coming through a light mist. The method has also the advantage that the lights are entirely outside the room, and the danger from fire is accordingly remote.

In the course of a discussion on this subject, opened by Prof. Silvanus P. Thompson at a meeting of the Illuminating Engineering Society (London) in 1914, several artists pointed

out that the light should be arranged to fall on the pictures, but that the spectators should be left in comparative shadow, just as the auditorium is darkened in a theatre. It was suggested that an adjustable canvas screen should be placed under the skylight, blocking the light immediately underneath but allowing it to pass unobstructed on to the pictures lining the walls.

It might be supposed that in an art gallery, where colouring is an essential feature, a quality of light identical with daylight, giving true colour values, would be preferred. There would seem to be an opening for the "artificial daylight" methods described in Chapter VI. On the other hand, a different view is occasionally taken. For example, in some galleries in private houses the appearance of the elaborate gold frames is considered an important feature, and we have met cases in which carbon electric filament lamps were preferred to tungsten lamps, on the ground that the latter made the frames appear like brass, and the rich gold colouring obtained from the ruddier illuminant was lost.[1]

Shop Lighting.

Artificial lighting is an important item to the modern shopkeeper. In past years, when the streets were so feebly lighted and means of locomotion were much less perfect than they are now, people did almost all their shopping in the daytime. As soon as night had fallen the streets became empty and merchants put up their shutters. But now the evening shopping is often a most important part of the day's trade. People flock into the streets in the evening; at Christmas time the brightly lighted windows are looked upon as one of the sights.

A distinction should be drawn between the illumination of the windows and the lighting of the interior of a shop. A number of papers have been read dealing with both aspects. We may mention particularly those of Stockhausen,[2] Prangnell and Broadberry[3] in this country, and those by Henninger,[4] and Law and Powell[5] in the United States.

[1] See a discussion at a meeting of the Illuminating Engineering Society, London, 17th Feb. 1914.

[2] *Illum. Eng.*, London, vol. i., 1908, p. 289.

[3] *Ibid.*, vol. v., 1912, pp. 123–156, 201–214.

[4] *Trans. Am. Illum. Eng. Soc.*, vol. vii., 1912, p 178.

[5] *Ibid.*, p. 537.

[illegible] windows naturally varies much according [illegible]. In a poor part of the town one does not [illegible] effects. The chief aim is merely to [illegible] illumination so as to attract the passer-by. [illegible] of trade window lighting has already [illegible]. An enterprising merchant recognises that, [illegible] costly site and expensive building, he [illegible] out of it: and that a well-lighted [illegible] the best possible advertisements. Such a

Fig. [illegible].—Showing the lighting of windows in Harrods' Stores (London) by concealed lamps.

window stands out from its darker surroundings and attracts attention more easily by night than during the daytime. It is therefore becoming customary for large stores to keep their display windows lighted after the shop has been closed to customers. In some shops a time switch is used which automatically extinguishes the lights at a certain hour in the evening.

In the better class of shop window the lighting is arranged in a manner resembling that of the stage, which is brilliantly lighted by concealed lamps and stands out in the darkened auditorium, thus naturally forming the chief object of interest. In the same manner, in lighting a shop window the merchant

provides a generous illumination by concealed lamps, usually spaced along the top of the window.

Windows may also be lighted by lamps placed entirely outside. In this case it is desirable that the side of the lamp facing the street should be screened so as to avoid glare in the eyes of drivers of vehicles and passers-by. The use of unscreened powerful lamps is sometimes defended on the ground that they act as an advertisement. But the functions of attracting notice and illuminating the goods should not be confused with one another. A lamp which attracts attention and then dazzles the

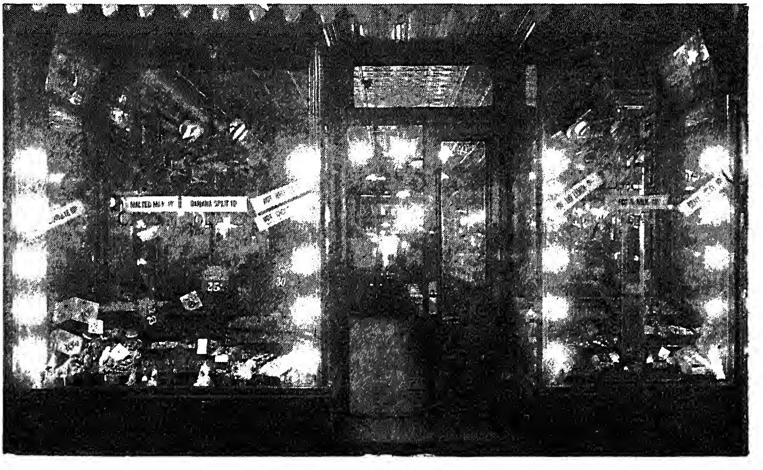


FIG. 172.—A poor arrangement.

The bright lamps dazzle the eyes of people looking in at the window, and relatively little light is shed on the goods.

observer defeats its own object. In some cases diffusing translucent screens, carrying the name of the shop, are used to cover the lamp; and, from an advertising standpoint, decorative and novel screens would seem preferable to merely exhibiting a bright lamp. In outside lighting some care is necessary to avoid inconvenient reflection of lamps from the glass of the window.

Concealed lights inside the window probably yield the most artistic results. As an example of what can be done in this respect we reproduce, fig. 171, a view of one of the windows in Harrods' Stores. Contrast this with fig. 172, showing the effect of bare metal-filament lamps spread among the goods. Unscreened lights should never be placed among the contents

at the window. They are wearisome to the eye, distract the attention from the very things they are intended to illuminate,

Fig. 173.—Window lighted by concealed lamps—a much better method.

The sources of light are screened from view and a strong illumination concentrated on the goods in the window.

Fig. 174.—Window lighting by gas lamps, screened on the side facing the roadway.

The reflectors concentrate the light on the window and screen the mantles from the eyes of passers-by.

and greatly impair the general effect of the display. When placed close to goods of an inflammable character they may be dangerous.

The reflectors used with a row of lights above the goods should be selected according to the size and depth of the window illuminated. Some examples of reflectors, suitable for windows of various dimensions, and the corresponding polar curves derived from them, were given by Henninger (*loc. cit.*). Another method occasionally employed is to box in the window with panels of diffusing glass placed above the goods, and to mount the lights in concentrating reflectors above this screen. The diffusing effect of this arrangement is very good; it has the advantage that the lights can be kept entirely out of the window area, and may receive attention without disturbing the display. In the case of gas lamps this is a special advantage, and might enable such lamps to be used in cases where the existence of products of combustion would otherwise be a drawback. This same method has occasionally been used in connection with arc lamps in the manner shown in fig. 175. The lamps are arranged so that they can be withdrawn at the side of the window for trimming.

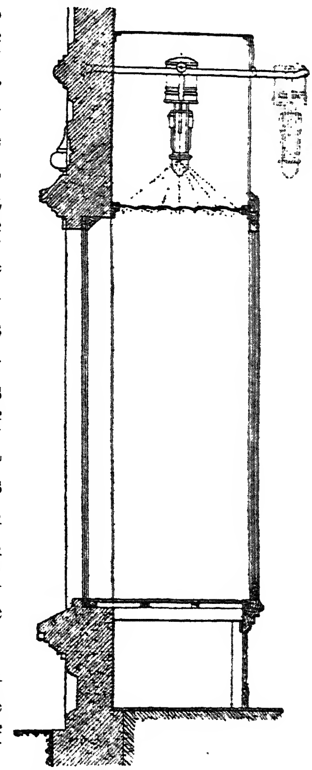
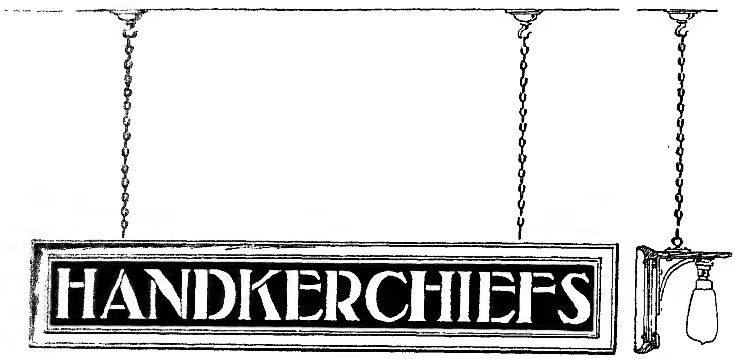


FIG. 175.—Showing arrangement enabling flame arc used for shop-window light to be concealed from view and drawn aside to receive attention when needed.

Another method of lighting which has proved very popular during the last few years has been the use of reflector signs of the type shown in fig. 176.[1] These are fitted with diffusing glass on the side facing the street. The white surface of this glass helps to concentrate the light on the goods behind, and may carry a name, motto, etc. A somewhat similar principle is sometimes combined with the roof system of lighting above glass panels, referred to above. The majority of the light in such cases is concentrated downwards, but a certain amount may be allowed to be emitted so as to illuminate a facia sign carrying a name plate and placed along the top of the window.

[1] See Prangnell, *loc. cit.*

The intensity of illumination required in shop windows is frequently high: for example, in Harrods' windows the surface brightness of the light-coloured goods approaches 15 to 20 foot-candles. In the paper by Henninger a consumption of electricity of 1·25 watts per cubic foot of space lighted was stated as a usual figure. For window lighting it seems preferable to use this method rather than to state the consumption per square foot of floor area, as the light is needed to illuminate vertical surfaces as well as horizontal, and allowance must be made both for the height and depth of the window. The amount of light provided in a window is naturally settled by other than



Front elevation. Section.

FIG. 176.—Arrangement of sign reflector to denote a particular department.

purely utilitarian considerations, the intention being to produce a striking and spectacular effect.

It may be observed that the illumination is in some measure a function of the quality of goods displayed. If these consist of dark materials, which reflect little light, a higher illumination will be necessary than in the case of light goods (such as silks and cottons). It is very essential that the light in these cases should be well diffused by reflection, so as to strike the objects on view from many different directions; for this reason it is usually easier to produce a good effect in a window containing light goods than in one which contains mainly dark and heavy things. The background is of some importance. It should be selected to harmonise with and display the goods to the best advantage. A light material is often of considerable assistance to the illumination; glass partitions, although often preferred by the merchant, are a drawback from the lighting standpoint,

giving rise to inconvenient reflection. The illumination, although well diffused, must not be entirely without shadow. Otherwise the window will appear somewhat flat. For example, in a discussion of the papers by Messrs Prangnell and Broadberry, in 1911, Mr V. H. Mackinney mentioned a case in which light coming at an angle was deliberately superimposed over the main illumination. This was needful in order to show some shadow on the face of a figure in the centre of the window.

In considering problems in shop-window lighting one is often forced to consider the method of arranging the goods at the same time. Window dressing and window lighting ought, strictly speaking, to be considered together.

It will be observed that there are two distinct ideas in shop-window dressing. In some shops the general idea is to make the window a catalogue of the contents of the shop. The person in the street inspects the window with a view to identifying something he wants; if he does not see it he probably passes on, and the shopkeeper too assumes that anybody entering the shop has made up his mind what he wants to buy.

Quite a different view is taken of the functions of many of the best shop windows. The merchant seeks rather to produce a novel and striking effect by collecting together and skilfully arranging a few choice goods. This display serves to attract people and acts as an advertisement; customers only begin to look for the object desired after entering the shop. The window is a choice sample rather than a catalogue.

This method is the most convenient for the production of artistic effects, and windows so arranged are much more readily illuminated than those that are crowded up to the very top with a miscellaneous collection of small articles; here each object is apt to throw a shadow on the adjacent one, and the light is only diffused with difficulty. If the goods are brought very near the glass, outside lighting may be a necessity.

Let us now turn to the lighting of the interiors of shops. Here again the value of good illumination is unquestionable. In gloomy and ill-lighted shops the assistants will probably have difficulty in finding things promptly, and the service suffers. Bad lighting is also conducive to misunderstanding. A customer who is served in a poor light probably leaves with a vague feeling of dissatisfaction and retains an unfavourable

impression as to the way the shop is conducted; or he may find that the object purchased looks very different in the bright illumination outside in his own home from what it did on the counter. It may be laid down as a general by-rule that goods should be inspected by an illumination not less than that under which they will subsequently be used.

The chief place where light is required is naturally the counter where goods are displayed. It is difficult to give any very definite figure, but from information available it would seem that in this country 3 to 10 foot-candles is very usual in well-lit shops. But besides lighting the counter the lamps should be arranged to give sufficient vertical illumination on the shelves behind. It is a very usual plan to arrange the lights in a long row down a gangway. This method is naturally not so satisfactory as if the lights were placed immediately above the counter, but may give fairly good results if the right type of shades are used and the ceiling is light in tint. But if inadequate shades are used, and the lamps are hung too low, insufficient illumination on the counter is probable, and it is likely that the customer, in trying to examine objects, will find himself in his own shadow. As in the case of window lighting, the nature of the goods has an important influence. An especially strong illumination should be provided for showing off dark materials.

In lighting large departments the need for *flexibility* in the system should be borne in mind. Not only is the arrangement of the goods altered from time to time, but the dividing up of the space and erection of partitions may completely change the character of the intérior.

A distinction may be drawn between the needs of small shops where the counter lighting is the chief consideration, and large stores where a bright general illumination over considerable area is needed. For the latter purpose indirect and semi-indirect lighting seem to be attracting notice, and have some distinct advantages. But judgment is necessary to avoid the defect of "flatness." Shop lighting, without being glaring, should be stimulating rather than "restful." It seems probable that indirect and semi-indirect lighting would answer best in rooms containing a fair amount of polished goods—such as furniture, china, etc., which shine and sparkle to some extent and give a certain amount of "life" to the display. From this standpoint semi-indirect lighting might be preferable to total

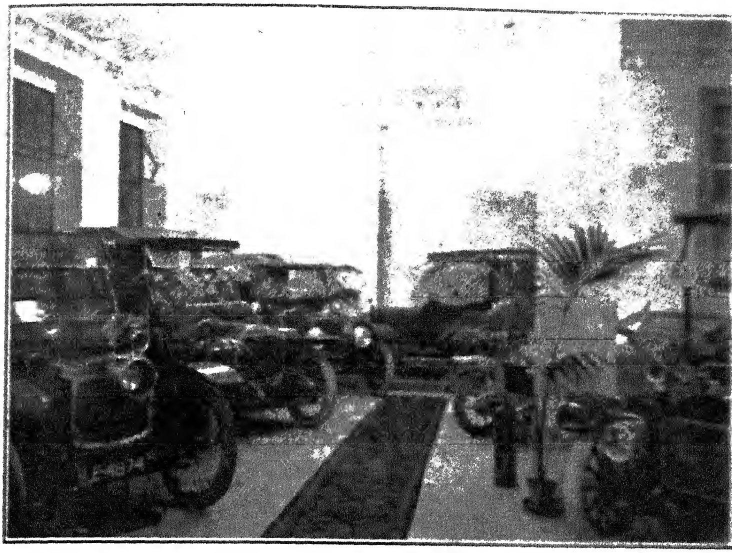


FIG. 177.—A motor car show-room lighted by tungsten lamps [illegible]

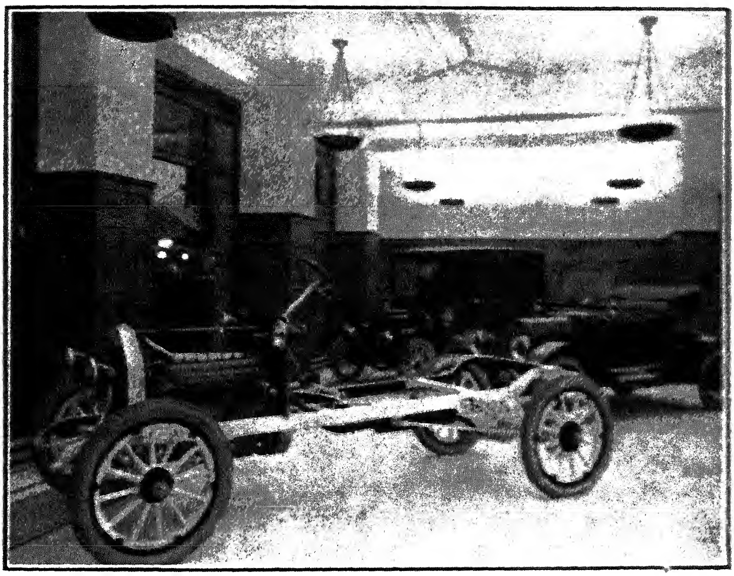


FIG. 178.—A motor car show-room lighted by indirect [illegible]

indirect illumination where there may be no very bright surfaces to undergo reflection, and therefore a deficiency in sparkle.

In certain cases, such as the illumination of jewellery, sparkle is an essential feature, and sources having a high intrinsic brilliancy should therefore be employed. Such sources are, however, to be screened as far as possible from the eyes of customers. There are other cases — rooms containing motor cars, bulky machinery, etc.—where good diffusion may be so vital as to reconcile the merchant to the somewhat mild effect of pure indirect lighting.

As a special instance of the applicability of indirect and semi-indirect lighting we may mention a barber's shop. Here the customer leans back in such a position that he must look towards the source. The barber requires a strong illumination on the customer's face, and if direct lighting is used it seems almost inevitable that the eyes of customers should be dazzled. But with an indirect or semi-indirect system the glare is largely absent. The good diffusion would probably be an advantage in illuminating the face of the person about to be shaved, since it would mean that it was lighted up by rays coming in many different directions. One might multiply instances where special methods of lighting are necessary, according to the nature of the trade. A typical example is afforded by those trades in which the appearance of colours is of consequence—for example, in a draper's shop, a florist's, or a picture dealer's, etc. It is possible that in many such shops some form of artificial daylight may prove of value.

Illumination for Games played under Cover.

There are many ball games that can be played under cover, and there has recently been quite a brisk development in covered courts for lawn tennis, racquets, and the like. In our climate it is naturally a great advantage to be independent of the weather, and it is now becoming customary to provide artificial lighting, enabling the game to be played independently of daylight as well.

Comparatively few people can spare much time for games during the day. Yet it is only in the summer that much play is practicable in the evening; during the short winter days the hours of play are much restricted, and there may even be times

when the light is so poor that nothing can be done. To the busy man, therefore, the possibility of being able to indulge his pastime during the evening by artificial light means a great deal.

Swimming-baths, gymnasiums, etc., have been lighted artificially for years. The requirements in both cases are simple—the provision of a well-diffused general illumination by lamps

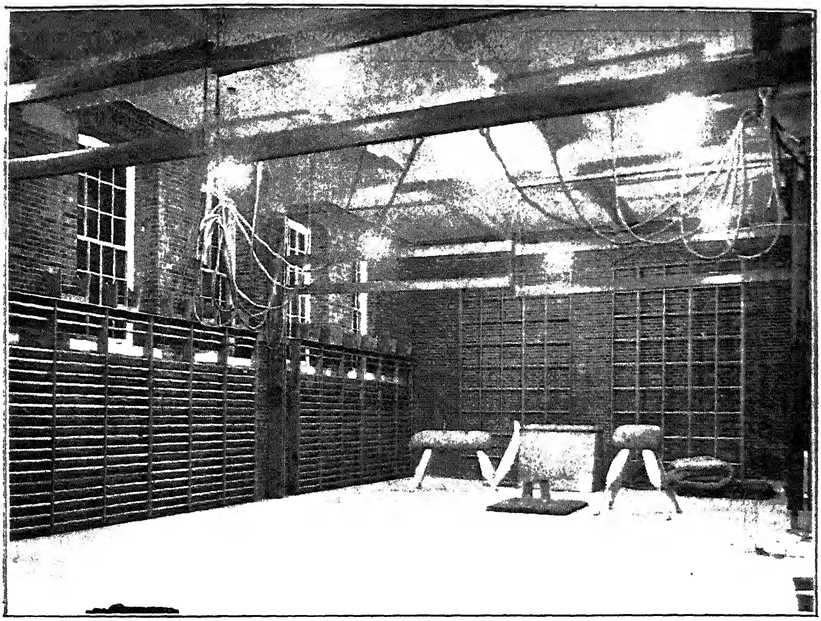


FIG. 179.—A gymnasium lighted by tungsten lamps in Holophane reflectors. placed high up out of the line of view.

placed high up out of the range of view. In fig. 179 we reproduce a view of a gymnasium so lighted.

But the lighting of areas devoted to ball games is a more complex matter. The conditions of illumination necessary to enable the eye to follow the rapid flight of a ball need to be studied very carefully, and will be found to vary considerably in the case of different types of games. Anyone attempting to illuminate, say, a lawn-tennis court should be himself a player, or should at least have the advice and co-operation of someone who is thoroughly familiar with the game.

Until about five years ago the use of artificial light for

games of this kind does not appear to have received much attention, and even now there are not many successful installations. About four years ago a description of the artificial illumination of a baseball ground in Cincinnati, U.S.A., was published;[1] and Rolph has described the method of lighting bowling-alleys in some detail.[2] In the former case the lighting was accomplished by a series of large projection arc lamps.

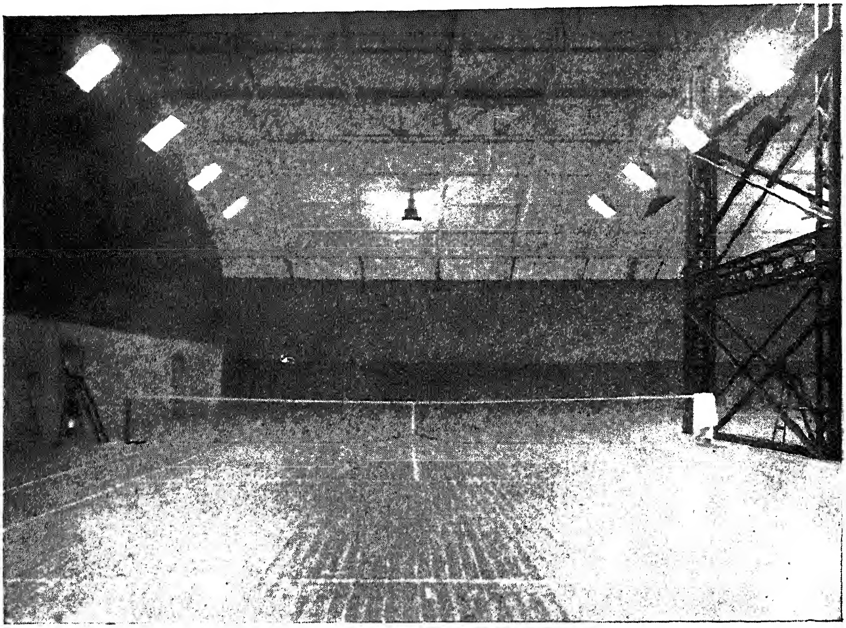


FIG. 180.—View of high-pressure gas lighting installation at Dulwich covered lawn-tennis courts, showing methods of shading.

The chief feature in the lighting of a bowling (skittle) alley is the screening of the lights in the direction facing the player, and the provision of a powerful illumination to display the pins at the end of the alley. It appears that the best results are obtained with an illumination of about $\frac{1}{2}$ foot-candle at the commencement of the alley, gradually mounting to 3 to 5 foot-candles at the end where the pins are situated.

T. J. Litle has described the gas lighting of lawn-tennis courts,[3] and also of a green devoted to the practice of "putting"

[1] *Illum. Eng.*, U.S.A., vol. iv., 1909, p. 301.
[2] *Trans. Illum. Eng. Soc. U.S.A.*, vol. v. p. 586.
[3] *Illum. Eng.*, London, vol. v., 1912, p. 502.

by devotees of golf.[1] Portable acetylene flares have also been used to illuminate bowling-greens by night, but these were essentially outdoor installations and hardly come within the scope of this chapter.

Two of the most interesting installations so far described are the covered lawn-tennis courts at Dulwich[2] and Liverpool,[3] designed by Mr H. M. Rootham, and lighted respectively by

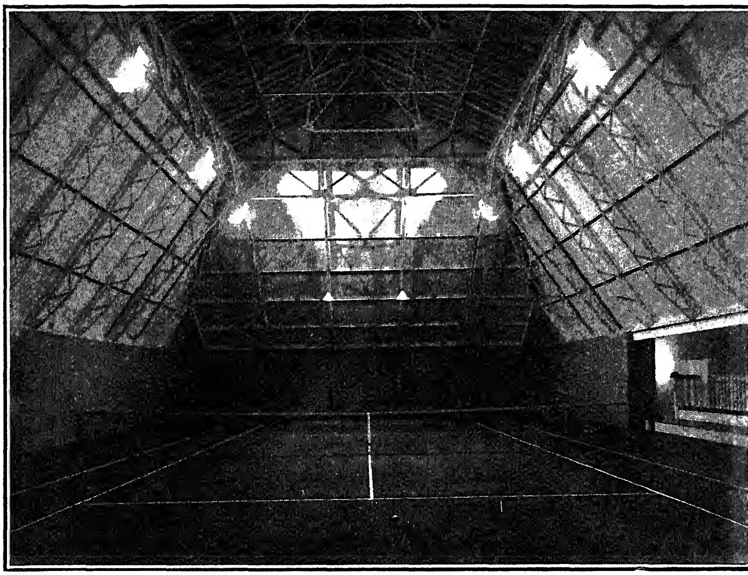


FIG. 181.—View of covered tennis court at Liverpool, showing side-lighting by tungsten lamps in special reflectors.

high-pressure gas and electricity. Views of these courts are shown in figs. 180, 181. In both cases four lamps are spaced down each side of the court and equipped with special reflectors screening them from the eyes of the players. At Dulwich gas lamps stated to give 1500 c.p. were used; at Liverpool 1000-c.p. tungsten lamps. There are also lamps in conical shades at either end of the court, so as to produce a specially strong illumination near the service line and enable a player to observe his opponent closely when in the act of serving. The actual illumination on the courts at Dulwich is about 3 foot-candles.

[1] *Illum. Eng.*, London, vol. vi., 1913, p. 299.
[2] *Ibid.*, vol. iv., 1911, p. 273.
[3] *Ibid.*, vol. vi., 1913, p. 507.

The consumption of electricity per court at Liverpool is approximately 10 units per hour; at Dulwich each court requires about 250 cubic feet of gas per hour.

In order to render the white balls clearly visible, and also to avoid multiple shadows from the moving ball, the court surface is painted a dead black. In the Dulwich court the background is also black, but at Liverpool a light-green colour was preferred. It is possible that indirect lighting might be still more suitable for lighting a lawn-tennis court, but in practice the system is usually rendered impracticable by the fact of the roof being mainly utilised for a skylight to illuminate the court in the daytime. It is, however, possible to derive considerable assistance by reflection from light walls. The daylight illumination also deserves some care. It is preferable to arrange the skylight in such a way that direct sunlight never strikes the playing surface of the court; in northern latitudes, where the sun is never directly overhead, this is quite practicable. In view of the intimate connection between the lighting of a covered court, the method of staining walls and floor, and the arrangement of the windows, it is very desirable for the planning of the building and the lighting to be worked out together.

There are other ball games, such as fives and squash racquets, that may also be carried on by artificial light. In these cases a black ball and white surroundings can be used, which is favourable to good diffusion and greatly simplifies the lighting problem. A number of squash-racquet courts have been erected by Mr Rootham and lighted on a uniform plan by overhead tungsten lamps in five Holophane bowl reflectors. The consumption of electricity for such a court would probably be about ½ unit per hour, and the resulting illumination about 2 foot-candles.

The lighting of Badminton courts is a simple matter, as the shuttlecock travels comparatively slowly and is easily followed by the eye. The chief point is to screen the lights and to place them well up out of the range of vision of the players.

A by no means unimportant problem is the lighting of rifle ranges. The chief essential here is to provide a strong and even illumination over the targets, the actual sources of light being concealed from the eyes of the firing party. The lights should be controlled at the end from which firing takes place.

DECORATIVE AND SPECTACULAR LIGHTING.

In concluding this chapter a reference may be made to the latent possibilities in the use of artificial light for artistic and decorative effects. In the last chapter it was remarked that there is great scope for taste and ingenuity in the design of fixtures, and the same applies generally to many problems in interior illumination.

Light and art must always be closely associated. The nature of this luminous image depends on the manner in which the surrounding objects are illuminated, and it is only through the rays of light reflected from such objects that they become visible at all.

Architectural effects do essentially appeal to the eye. Having so many centuries of tradition behind it, decorative and architectural design has naturally been governed by the appearance of objects as seen by daylight. Such arts date back to the time when artificial illuminants were in a primitive condition, and had little influence on social conditions. But in this century the proportion of our lives spent under artificial light is far greater. Important social functions and gatherings now take place mainly in the evening, and many of our buildings are actually used more by artificial light than in the daytime.

It should therefore be a matter of interest to the architect how an interior is lighted. The use of carelessly placed lamps and imperfect methods of screening may entirely destroy the charm of an interior; tasteful methods of lighting may enhance it. Moreover, artificial light is much more completely under man's control than daylight. In the theatre—essentially a building for *evening* entertainment—this conception of light as a decorative agent has already made considerable headway, but there is no reason why it should not be applied in many other classes of buildings.

Before any great advance in this direction can be made, it is essential that the lighting should be regarded as an integral point in the architectural design, and deliberately planned out simultaneously with the structure of the building. An illustration of the benefit of such co-operation has already been provided by the lighting and design of covered lawn-tennis courts. But here the object of the lighting was strictly utilitarian. When we are aiming at a decorative effect the possibilities are infinitely greater. Mr H. B. Lanchester, F.R.I.B.A., in a paper before the

Royal Society of Arts (London) on "The Design and Architectural Treatment of the Shop," recently remarked that the resources of artificial lighting are rarely sufficiently exploited, and the same holds good for many other classes of buildings (hotels, restaurants, clubs, public halls, etc.) where the evening may be the most important period.

The practical details of such co-operative schemes remain to be worked out. Even the principles involved in the use of light for decorative effect are by no means established. Such matters as the desirable brightness of sources of light in comparison with that of the walls and surroundings; the relative amount of light to be allotted to the floors and upper parts of rooms, executed in various architectural styles: the conditions of shadow desirable, and their use in emphasising fluted columns, alcoves, carving, etc.: the placing of sources above ceilings and domes, or in niches and mouldings; the illumination of frescoes; and the infinite possibilities of subtle colour harmonies—all these have only been investigated by the few. Special reference may be made to various papers published in the United States by Mr W. Bassett Jones,[1] and particularly his account of the lighting of the Allegheny Memorial in Pittsburgh, on which something was said in Chapter VI. (p. 199).

Again it is often necessary, for the sake of symmetry, to mount lights at certain points on the ceiling, or on certain pillars, etc., and in positions that are really determined solely by the design of the architect. If these positions are settled without reference to the lighting requirements of the room, the lighting engineer finds himself in a difficulty. He may either place the lights where they obviously "look best" and run the risk of getting unsatisfactory distribution of illumination; or he may determine to place the lamps so as to give the light where it is really needed, but may, in so doing, prejudice the general appearance of the room.

As an illustration we may take such interiors as museums and libraries. The ceiling is not infrequently divided up in such a way that the chandeliers have to be hung over the gangway—a position that is rarely satisfactory from the lighting standpoint. Or, again, the lighting engineer may come to the conclusion that

[1] See "The Relation of Architectural Principles to Illuminating Engineering" (*Trans. Am. Illum. Eng. Soc.*, Jan. 1908); "Lighting of the Allegheny County Soldiers' Memorial" (*Trans. Am. Illum. Eng. Soc.*, Jan. 1911); "Problems in Interior Lighting" (*Proc. Am. Inst. of Elec. Engineers*, June 1912).

indirect lighting is the ideal thing in a certain room—only to find that the type of ceiling makes it impracticable.

Such problems as those mentioned above fall mainly within the province of the artist and the architect, but the co-operation of the lighting engineer may be needed in order to carry them out.

The production of the scenic effects in the theatre, which have played an increasingly promising part in theatrical enterprises during the last few years, is a somewhat special branch of spectacular lighting, but often demands a high order of artistic skill. The methods by which these effects are produced are most elaborate. Batteries of coloured lamps in reflectors, the brightness of which can be adjusted by rheostats, are usual, and by this means the resultant colour-tint can be gradually modified to imitate the effects of twilight, moonlight, sunset, etc. Sometimes, in order to secure very delicate colour effects, reflected light from tinted fabrics is utilised. The mercury-vapour lamp is said to have proved particularly serviceable for imitating moonlight, and it is possible that other new illuminants, such as the neon tube, which gives such a pronounced orange-red light, may also have special uses. Equally interesting are the various devices for imitating moving clouds, rain, etc. These are usually produced by projecting from a lantern an image of a rotating disc on which suitable patterns are traced. The rate of rotation is slow and the arc on which the image moves considerable, so that falling rain, hail, etc., can be readily imitated. Another modern stage-appliance is the cinematograph. It is possible that the new methods of projecting "solid figures," with an invisible screen, may prove a still more useful asset (especially in "ghost scenes!").

With all these appliances at his command the stage illuminating engineer should be able to produce remarkably decorative effects, and indeed the stage is already a striking example of what the combined efforts of the artist and the engineer can accomplish.

CHAPTER X.

OUTDOOR LIGHTING.

Street Lighting, its Historical Development—Requirements of Streets for Safety, and as regards Traffic—Effect of Motor Traffic and Increased Speed—Recent Developments in London and other Cities—What constitutes good Street Lighting—Requirements of various Classes of Streets—Lighting by Posts, Brackets, and Central Suspension—Powerful Lights high up, and Small Units near together—"White Way" Lighting—Lighting of Country Roads—Need for Central Control—Artistic Aspects of Public Lighting—Conversion of Old Lanterns—Lamps outside Public Buildings—Lighting of Squares, Parks, and Bridges—Illuminated Signs—Outlined Letters, Transparencies, and Bead-Signs—Uses of Illuminated Signs and Notices—Vehicle Lighting—Headlights for Motor Cars—Lighting of Tramcars and Railway Carriages—Illumination of Railway Platforms, Booking Halls, Corridors, etc.—Devices on the Underground Railways—Ship Lighting—Decorative and Spectacular Lighting—Conclusion.

THIS, the final chapter of our book, deals with "outdoor lighting." Under this heading are included such matters as street lighting, the illumination of yards and railways, spectacular lighting, etc.; but something may also be said on the lighting of vehicles, railway carriages, and ships, which, while in a sense constituting illumination under cover, have to do with the conveyance of people out-of-doors, and are therefore conveniently considered at the same time as outdoor illumination.

STREET LIGHTING.

In the first chapter of this book we sketched the development of public lighting in times gone by. It was remarked that in past centuries the only form of light in the streets was provided by individual householders, whose duty it was to hang a lantern outside their dwellings during certain hours. Gradually, from being a purely private duty, street lighting fell into the hands of the authorities in the respective districts. This explains why, in such a city as London, which is divided [illegible]hs each controlled by their local representatives,

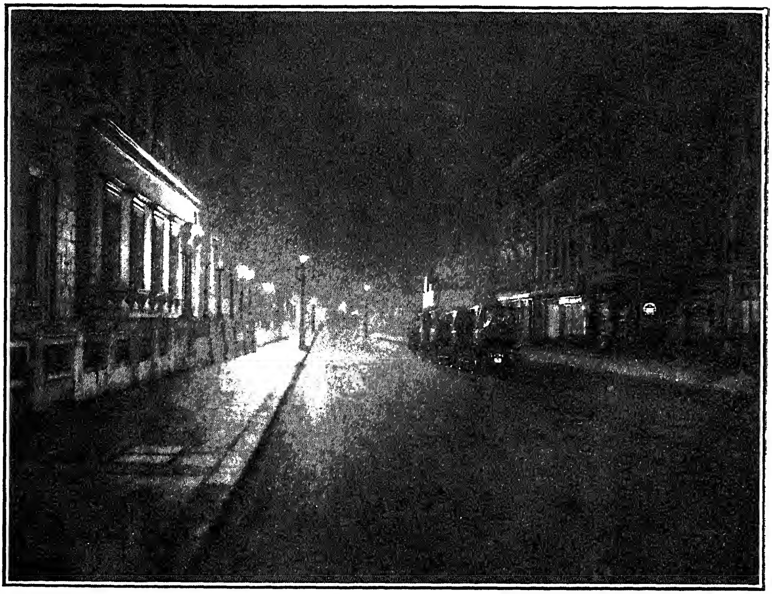


FIG. 182.—Lighting of Pall Mall, London, by high-pressure gas lamps "staggered" on either side of roadway.

This was one of the first streets in London to be lighted by gas at the beginning of the last century.

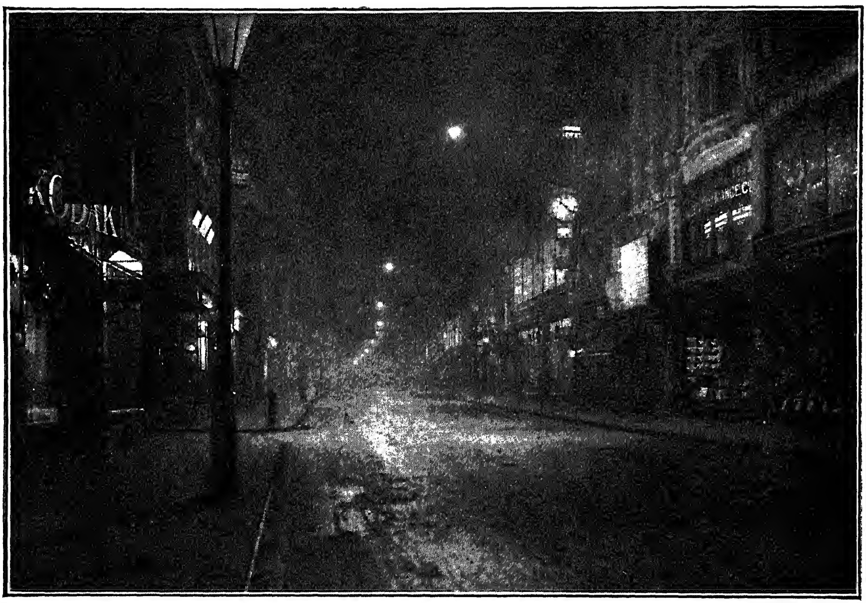


FIG. 183.—Night view of Cheapside, illuminated by Oliver flame arc lamps.

so many different methods of lighting are to be seen. A stranger, walking less than a mile from Holborn Viaduct to Oxford Street, may see in succession high-pressure gas, flame arcs, incandescent electric lamps, low-pressure gas, and again flame arcs: to visitors who do not know the circumstances these sudden transitions in the lighting naturally come as a surprise. As will appear shortly, however, there is some reason to expect that eventually public lighting will enter upon another phase, and that the present somewhat chaotic conditions will give place to more scientific treatment.

While the control of public lighting has developed, *its object* has also changed. One of the chief uses of the old oil lamps in cities was to aid the police in keeping order. The illumination can hardly have been sufficient to enable people to do more than see where the pavement ended and the roadway began.

Originally lighting was mainly a measure of safety and a means of revealing obstacles or imperfections in the roadway. Later the steadily growing stream of horse-driven vehicles called for a higher order of illumination. To-day the enormous increase in the speed and volume of motor traffic again demands new conditions.

The early papers of Trotter and Blondel contain much interesting discussion of street-lighting problems — problems which at that time were little studied outside strictly engineering circles. But within the last few years the introduction of many new illuminants, and the traffic problems referred to above, have forced these matters before the notice of public authorities. An important step, taken in 1909, was the appointment by the City of London of a deputation to visit the chief Continental cities, and report on the methods of lighting. Some of the cities in the United States had already sent representatives to Europe to study the subject, and still do so. The report of the deputation from London contains some useful data as to the methods of illumination then inspected and their cost.[1] Since that time important improvements have been made in the lighting of Holborn, Westminster, the City, and other districts in London, as well as in Manchester and other provincial cities. In England the methods adopted now resemble closely those generally adopted on the Continent, high-pressure gas lamps and flame arcs being used for the lighting of main thoroughfares, and low-pressure gas and electric metal-filament for the side streets. It

[1] *Illum. Eng.*, London, vol. ii., 1909, pp. 526, 623, 677.

remains to be seen what influence the new "half-watt" high candle-power metal-filament lamp will have on existing usage.

It is not proposed to enter into the cost of street lighting. Much depends on the local price of gas or electricity, the arrangement of the accounts, and the number of hours the lamps are allowed to burn. It may be noted that in the United States and in some Continental countries a moonlight schedule—*i.e.* an arrangement providing that the lamps shall be extinguished on certain nights during the year when it is presumed the streets will be sufficiently lit by moonlight—is still sometimes adopted. This practice was strongly criticised by Dr Louis Bell [1] in his presidential address before the American Illuminating Engineering Society some years ago, and is falling into disuse. In this country, at all events, the probability of the moon being obscured by clouds is too great for much reliance to be placed on this form of natural lighting; in any case, the intensity of moonlight is only comparable with that considered sufficient for streets of little importance.

Those interested in the cost of street lighting may be recommended to read the report of the deputation of the City of London, and the account of the recent contracts entered into in Westminster, Manchester, Boston, and elsewhere.[2] It may be observed that the street-lighting committee in Manchester recognised the importance of the subject by appointing two independent experts, Mr J. Abady and Mr Haydn T. Harrison, to report on the public lighting.[3] The illumination in this city was also discussed in a recent paper before the Institution of Electrical Engineers (London) by Mr S. L. Pearce and Mr H. A. Ratcliff.[4] Modern electric street lighting was dealt with in a paper by Mr Haydn T. Harrison before the same institution, in which detailed tables of cost were presented.[5]

[1] *Trans. Am. Ill. Eng. Soc.*, vol. iii., 1908, p. 400.

[2] See "Street Lighting of Westminster," report issued in 1910, *Illum. Eng.*, London, vol. iii., 1910, p. 299; "Public Lighting of Boston," *Illum. Eng.*, London, vol. ii., 1909, pp. 481, 531.

[3] "Public Lighting of Manchester," report issued by J. Abady and Haydn T. Harrison in 1912 (*Illum. Eng.*, London, vol. v., 1912, p. 534).

[4] "Recent Developments in the Street Lighting of Manchester," by S. L. Pearce and H. A. Ratcliff, *Proc. Inst. of Elec. Eng. London*, vol. l., 1913, p. 596.

[5] "Street Lighting by Modern Electric Lamps," by Haydn T. Harrison, *Proc. Inst. of Elec. Eng. London*, vol. xlvi., 1911, p. 24. See also "The Cost of Electric Street Lighting," by the same author, *Illum. Eng.*, London, vol. i., 1908, p. 903.

As an illustration of the vast improvements to be accomplished by the introduction of modern illuminants, may be mentioned the case of the City of London, where a combined scheme of high-pressure gas and electric flame arc lighting was recently adopted. As a result an increase of no less than 600,000 c.p. and a saving per annum of as much as £6700 is anticipated.

It will be seen, therefore, that it is of considerable importance to the local authorities to know the conditions under which gas and electric lighting are best employed—particularly in the large number of cases where both the electricity and gas supply are municipally owned. The competition between the two illuminants gives rise to much partisan discussion which is apt to mask the real issues. For this reason one of the authors recently urged the desirability of a central impartial authority to deal with the subject, under whose supervision authoritative and decisive tests could be carried out.[1] Such experiments need not be limited to comparisons between the two illuminants, but might include investigations into the general principles of street lighting. The need for such an impartial tribunal was illustrated in the case of the Manchester lighting, where the assistance of two independent experts was secured. There have been other indications that some form of understanding between the gas and electrical interest may be expected before long. Already, in the lighting of Holborn and the City of London, we have had instances of compromise, certain streets having been allotted to be respectively lighted by gas and electricity. The fact of a joint committee having been appointed to consider the framing of a standard specification on street lighting is also evidence of a desire on both sides to come to a general understanding as to what constitutes good street lighting.

A feature of recent street-lighting contracts has been the insertion of some clause specifying the actual candle-power of the lamps provided: for example, in the Westminster specification it was laid down that the candle-power of the lamps should be tested periodically at angles of 20° to 50° to the horizontal, the idea being that the mean of these two readings gave a fair estimate of the mean hemispherical candle-power.

We do not wish to re-enter now upon the vexed question of the relative merits of measurements of candle-power and illumination, which played such a great part in the discussion of Mr

[1] See "The Lighting of London," a paper read before the London Society on 10th Feb. 1914, *Illum. Eng.*, London, March 1914.

Trotter's paper on the street-lighting specification. The matter is still *sub judice*, and was touched on in Chapter VII. (see p. 263). But something more may be said on the general question "What constitutes a well-lighted street?"

One of the difficulties confronting those interested in the framing of a street-lighting specification was that no general agreement exists on this point. It appears, however, that the view is now usually held that *most* of the light should be concentrated below the horizontal, although it may be desirable to allow a certain amount to illuminate the faces of buildings and surrounding objects. Clearly, the most important function of street lamps is to illuminate the roadway and pavements and the people and carriages using them. From this standpoint, the method of measuring horizontal illumination has advantages. That is to say, leaving out of account its use as an adjunct to street-lighting contracts, and as a means of comparing rival illuminants, it is a good method of testing the distribution of light in streets, and probably the most convenient means of specifying the illumination various classes of streets require.

The table drawn up by the joint committee classifying streets in terms of the minimum illumination provided, is of exceptional interest:—

Classification of Streets.	Minimum Horizontal Illumination.
Class A	0·01 foot-candle
" B	0·025 "
" C	0·04 "
" D	0·06 "
" E	0·10 "

Streets having a minimum illumination of not less than 0·1 foot-candle (Class E) would presumably be important business thoroughfares. In many cases this minimum value would be considerably exceeded. The lighting of streets having less than 0·01 foot-candle minimum would come under the heading of "beacon lighting."

But apart from the minimum illumination provided in a street, the distribution of light is of great importance. From a theoretical standpoint it may be argued that in general every part of a street requires good illumination, and that therefore the illumination should be uniform, just as is usually required

in a well-lighted interior. But in practice the comparatively long distance between the lamp-posts makes it difficult to fulfil the requirement.

It has been pointed out by Millar,[1] that vehicles and pedestrians seen between the lamps are distinguishable chiefly as silhouettes against the bright background of light directly reflected from the more or less shiny surface of the street. This only illustrates one of the chief limitations of street and outdoor lighting, namely, that so little assistance is derived in the form of reflection from surrounding surfaces. In an ordinary room we have closely spaced lights and abundant reflection from walls, ceilings, etc., so that the light strikes objects from many different directions, and enables all the details to be clearly seen. But in streets, and in large yards and other open spaces, we have to depend chiefly on the direct rays from illuminants spaced at long intervals. Consequently the faces of approaching people are often in deep shadow, or are seen silhouetted as dark objects against the bright lights behind. Similarly, moving vehicles throw deep moving shadows which are apt to mislead the unwary pedestrian. In large cities, where the surfaces of buildings are usually grimy and reflect little light, this is very marked. In those more fortunate towns where the house fronts are white and can be kept so, the diffusion of light is much better and the difficulties of successful street lighting are considerably lessened.

Naturally there will also be cases in which an extra illumination may be desired at specially important points in a street, *e.g.* at busy crossings. It has also been pointed out that a driver passing from a dimly lighted side street into an important thoroughfare is apt to be dazzled by bright lights. In Stuttgart this has been provided for by "grading" the lighting of side streets, *i.e.* by gradually increasing the candle-power of lamps as the main street is approached, until the illumination at the extremity is as high as that in the main thoroughfare.

However, it is at present by no means easy to secure even approximate uniformity of illumination. By means of the special reflector mentioned in Chapter VIII., Mr A. J. Sweet anticipated that a diversity coefficient of 4:1 might be obtained, and Mr Harrison has recorded that in some Marylebone streets this ratio was as low as 6:1. But there are many streets in

[1] "An Unrecognised Aspect of Street Illumination," *Trans. Am. Illum. Eng. Soc.*, vol. v., 1910, p. 546.

London, and very brightly lighted ones too, in which the ratio between the brightest and darkest parts of the street is as much as 50 or even 100 : 1.

There is, moreover, one great obstacle to most methods of obtaining uniformity. In order to improve the illumination midway between the sources we may, by prismatic globes and other contrivances, accentuate the candle-power at angles slightly below the horizontal; it is these rays that illuminate the parts of the pavement most remote from the lamp where more light is needed. But in taking this step we are apt to accentuate the glare, for such rays, being inclined only slightly to the horizontal, are visible right down the street and strike straight into the eyes of drivers of vehicles. In street lighting, where the surroundings are so dark, the dazzling effect of brilliant sources is considerable, and there are some who consider that the recent increase of traffic accidents is due partly to the bewildering effect of modern high-power illuminants.

The problem, therefore, is to devise a means of directing the light to remote regions of the roadway without producing the impression of glare; in order to do this it would seem necessary to use some form of large diffusing globe spreading the source over a larger area and making its luminosity milder than at present. There can be little doubt but that more might be done than has been accomplished at present both with a view to softening the light and improving its distribution. For example, it may be desirable, for the sake of uniformity, to concentrate the rays of light on the part of the road intermediate between two lamps; but it is surely unnecessary for a powerful and brilliant light to be exposed to the eyes of people much further down the street. It is sometimes argued that the appearance of a long chain of lights is artistic and impressive, and that it helps to mark out the boundary of the road in a mist or fog. But it is possible to produce this effect without the intense brilliancy that is often used at present; in other words, one might allow a certain amount of light to escape out nearly horizontally so as to be visible afar off, but if these rays were masked and softened by some diffusing material the lights would still serve their purpose without being so glaring.

Brilliant lights at a low level are most objectionable. But even lamps hung 30 feet high or more, although out of the direct range of view at close quarters, are apt to appear glaring a little

distance off. It seems probable that in the future much more importance will be attached to the avoidance of glare in street lighting, and that efforts will be concentrated on the design of globes and lanterns of a more artistic kind, giving sufficient light but having a milder luminosity. The elimination of glare is so vital, that many people would be willing to make considerable sacrifices as regards efficiency and uniformity if necessary to this end; holding that with less light from well-screened lights we should nevertheless see our way about better than at present. It has even been suggested that there is a future for units of the semi-indirect type, the lower rays being intercepted by a diffusing hemisphere and the upper rays received on an enamelled reflector. While there are difficulties in the use of this form of unit, it is quite conceivable that in some streets it might be acceptable, especially when economy is not the main consideration.

One point that is apt to be overlooked by designers of units intended to give uniform street illumination is that in practice it is rarely possible to place the lamps as theoretical suggestions would suggest. In most cities, when a change of lighting is contemplated, the new illuminants have to be attached to the old lamp-posts already in position. Moreover, there are often cases in which the ideal spacing has to be interrupted owing to intersecting roads, street refuges, etc.

The present methods of arranging street lamps are practically four in number, namely: (*a*) lamps staggered alternately on either side of the street, (*b*) lamps arranged down the centre of the road (suitable only for wide streets), (*c*) lamps suspended on brackets from the houses and at the sides of the street, and (*d*) lamps suspended centrally over the roadway from wires spanning the street.

Of these, the first method is much the most usual, but it may (as in Whitehall, London) be supplemented by lamps mounted over street refuges. One of the best known instances of lighting from central standards is the row of standards, each carrying two flame arc lamps, in Oxford Street, London. The two other methods are in general only applicable in cases where the authorities have the right to make use of the surface of the houses lining the street for support. In the City of London both methods have been used. High-pressure gas lamps suspended on brackets have been used in Fleet Street, and the central suspension system (which was introduced much earlier on the

FIG. 184.—A view of Fleet Street formerly lighted by Keith high-pressure gas lamps on brackets.

FIG. 185.—Fleet Street as it is now (1914) lighted by centrally suspended Keith high-pressure gas lights.

Continent) is now used in Cheapside, Cannon Street, and other streets in the City.

The advantages of these respective methods have been much debated. The bracket system, and the use of staggered lamps on the curb would seem to have the advantage of removing the lights somewhat from the direct range of view looking down the street; on the other hand, a disproportionately large amount of light is often thrown on the walls of houses, adjacent hoardings, etc., which might well be devoted to the street, pavement, and roadway. When brackets can be used, the removal of the obstruction of lamp-posts is a decided advantage. But as the lamps are somewhat remote from the centre of the road, it is probable that this method alone would only be used in streets that are fairly narrow. The system of central suspension, which is now applicable both to gas and electric lamps, has likewise the advantage that lamp-posts are done away with and the pavement and roadway are left free to traffic. Moreover, with such sources as the flame arcs and the inverted gas lamps, which give a strong downward component, it is probable that a relatively larger percentage of the total flux of light can be concentrated over the road, where it is most needed. On the other hand, it has been urged that the fact of the lamps being immediately overhead is a disadvantage for traffic; it is apt to cast dense shadows and does not so readily illuminate the sides of cabs and 'buses as staggered lamps would do. It is also considered by some that the wires spanning the street are unsightly, and that they might prove an obstacle to the passage of fire-escapes.

In this country such suspension methods have been used mainly with the more powerful illuminants, but in the United States rows of glow-lamps of moderate candle-power have occasionally been used in the same way.

The tendency in modern street lighting has been rather in the direction of using more and more powerful illuminants, spaced comparatively far apart and hung at a considerable height. In one sense this may be regarded as tending in the same direction as natural lighting, where the light is received from a source of immense candle-power—the sun—very far away. It is interesting to notice that when electric arc lamps were first introduced there were some visionaries who predicted that an artificial system of illumination might eventually be contrived on these lines. Indeed, as far back as 1763, a project was brought forward by a M. le Fevre to illuminate London by a very power-

ful oil lamp placed on the top of a tower and equipped with four parabolic reflectors.[1]

The effect of a very powerful light at an immense distance is to produce good diffusion by reflection off surrounding objects in the streets, in the same way as the sun's rays. But there is a converse method of lighting which leads to very similar conditions, namely, the subdivision of sources. In one sense the conditions of illumination in the days when every householder had a light outside his own door were more scientific than

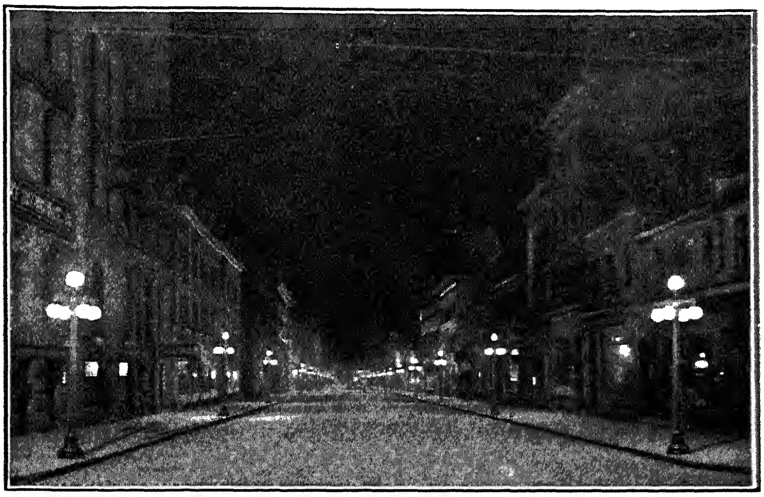


FIG. 186.—A street in Toronto lighted by clusters of tungsten lamps in Alba glass globes.

those prevailing to-day. The lights were too feeble to be of much assistance, but the subdivision must have been favourable to good diffusion and elimination of glare. There are some who consider that future methods of street lighting will proceed more on these lines.

The American practice of mounting on a post clusters of white glass globes containing tungsten lamps is illustrative of this method. In Mexico City a somewhat striking combination of cluster lighting on the pavement and centrally suspended flame arcs overhead is employed. At a certain hour at night the pavement lights are turned off, leaving only the flame arc lamps burning.

[1] *Illum. Eng.*, London, vol. iii., 1910, p. 159.

The Lighting of Country Roads.

When we come to the lighting of rural roads, outside the great cities, we find that we have to do mainly with "beacon lighting" lamps, that is, spaced at such long distances apart and of such comparatively low candle-power that they serve rather to mark out the edges of the roadway than to illuminate it to any great extent.

It was pointed out at the International Roads Congress, held in London in 1913, that the functions of country roads have gradually changed, owing to the more complete manner in which districts have been interconnected. At one time they were merely used for slow-moving local traffic; to-day they may carry rapid vehicles from quite distant parts. Moreover, in the neighbourhood of fairly large provincial towns such roads may be crowded by special traffic depending on the local trades and markets. In recent years this traffic has grown immensely in volume. It is said that in the plains of Lombardy the roads are often densely crowded by night, the market traffic during some seasons of the year being too huge to be transmitted during the daytime only.

In such cases the nature of the artificial lighting is surely of consequence, and equally so in the case of main roads which are largely used by long-distance motor traffic. There are many other points besides the actual lighting of the road surface that deserve attention, and were considered at the Congress referred to above. For example, there is the question of the illumination of direction signs and finger-posts, the provision of suitable lights to mark the condition of level crossings, or obstructions and excavations in the roadway, etc. One very practical suggestion is that the woodwork of such obstructions should always be painted *white*, so as to stand out readily from the dark surroundings and become a marked object when illuminated by the searchlight of an automobile.

It may be observed in passing, that the change in the surface of many of our main country roads is not without influence on the illumination. The substitution of a dark tarred surface for the customary macadamised light material means that the surface brightness of the illuminated road is less, and that it does not stand out so distinctly from its surroundings. On the old roads the motorist saw the roadway stretching ahead like a white ribbon between the dark hedges;

but with a tarred surface there is less contrast of this kind to be seen, and the motorist requires a proportionally more powerful headlight.

The fact that so many country roads are now used mainly by visitors from afar, and not by local traffic, and that their lighting requirements are now quite different from what they were in the past, has led some people to contend that the care of main roads connecting large towns ought to be undertaken by the State; and that the value of these important arteries of traffic is national and not parochial. Similarly, a recent Departmental Committee recommended that a special board should be formed to control the traffic (and presumably the roadways) of London. One of the most striking things at the recent International Roads Congress was the assumption of the various speakers that upkeep and lighting of roads should be considered together. Both should come under the control of some central authority.

Artistic Public Lighting.

So far we have spoken of street lighting mainly from the purely utilitarian standpoint of enabling people to recognise surrounding objects and to see their way about. But besides the duty of authorities to the public in this respect, there are other good reasons why the control of public lighting should be centralised and why the whole question should be esteemed more highly.

People scarcely realise how much the appearance of a city by night depends on the artificial illumination. We are still emerging from the tradition that the life of a city ceases when the sun has gone down. This is now very far from being the case. On the contrary, it is only after sundown that most people are set free to enjoy themselves, and most places of entertainment derive by far the greater part of their revenue from the evening hours. Many people, it is safe to say, use the streets more by night than they do by day, and they have certainly then more leisure to observe them in the evening.

If, therefore, it is the duty of civic authorities to supervise the planning of their cities, to scheme out the streets, bridges, and public buildings so as to be an architectural delight rather than an eyesore, it is surely worth while to consider how these

features will appear in the night-time. In main thoroughfares, artistic considerations ought surely to be given an important place, and the design of lamp-posts and lanterns should be taken up from the æsthetic standpoint. Some years ago an article in *The Builder* criticised severely many of the lamp-posts of London,[1] and there is no doubt that the same objections might be taken to the designs in most cities. The same point was referred to by Mr C. F. Lacombe in a recent paper on the street lighting of Greater New York. He showed a number of the latest designs adopted in that city, in which an attempt had been made to reconcile artistic and practical considerations, each design being finally submitted to the Art Commission before acceptance.[2]

The design of lamp-posts is the more important because they form such prominent objects in the streets by day, as well as by night. But there would seem to be also unexplored possibilities in the design of globes and lanterns surrounding the illuminants themselves. In lighting a beautiful interior no expert worth the name would dream of using lamps just as they are turned out by the manufacturer. On the contrary, he uses all his skill in selecting fixtures suited to the room, and in softening the light from the illuminant by concealing it in suitable diffusing glass globes, reflectors, or bowls, or by the use of silk or other translucent materials. Yet in the streets, and outside buildings, we find both gas lamps and arc lamps in use in exactly the form they are turned out by thousands from the works, a form which is determined almost entirely by purely practical points affecting their operation, and scarcely at all by the artistic requirements of the situation. In the same way when old lanterns are converted to gas or electric light there is commonly little artistic ingenuity shown. All that is done is to insert a gas burner or metal-filament lamp without any consideration whether the new illuminant is suited to the old fitting, or whether it could not be better arranged to show off its charm. In the case of these old lanterns, which are equipped with beautiful ironwork, there would seem to be one obvious and simple step: namely, to replace the clear glass by some diffusing variety so that the lantern appears mildly illuminated all over, presenting a background against which the ornamental frame can be seen as a silhouette. Placing a small source of high

[1] August 21, 1909.

[2] *Trans. Am. Illum. Eng. Soc.*, May 1913.

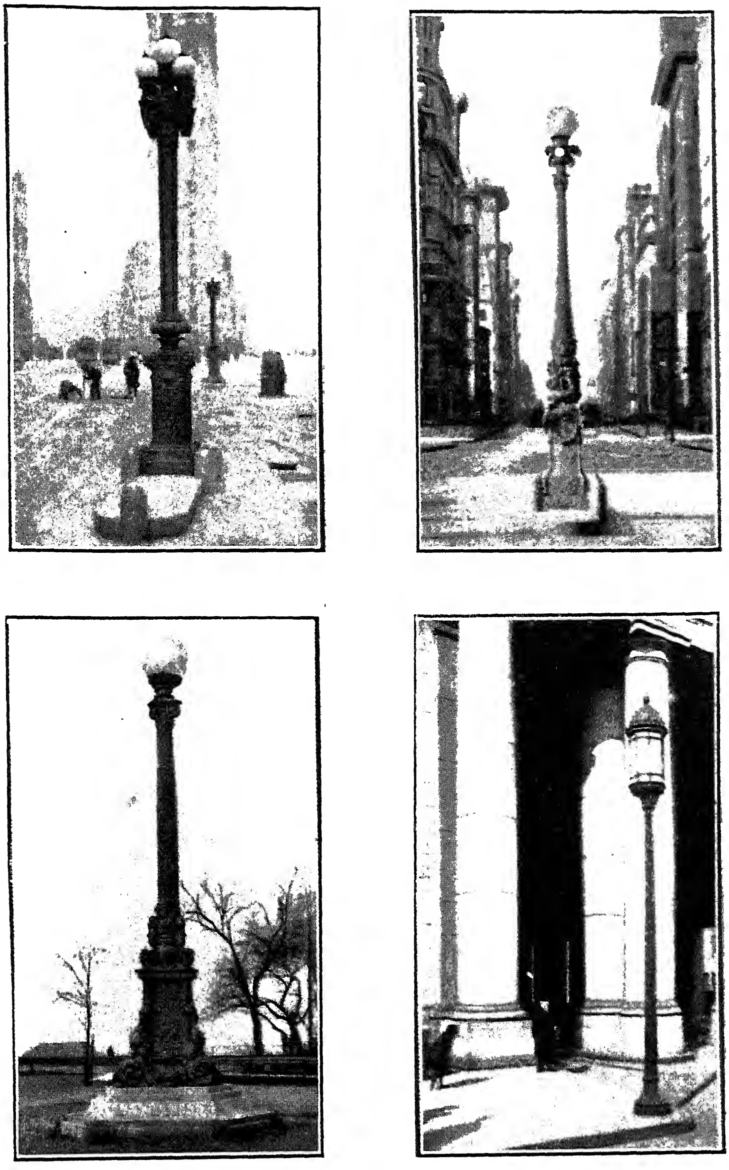


FIG. 187.—Some artistic lamp-posts described by Mr C. F. Lacombe. (*Trans. Amer. Illum. Eng. Soc.*, May 1913.)

intrinsic brilliancy within clear glass only means that the outlines and metal-work become indistinguishable; they are seen either against a dark background or against the bright source, and in either case can only be examined with extreme difficulty.

There is a special opportunity for artistic skill in the design of lamps outside new and important buildings. A fine effect might often be obtained if these lamps and the architectural features of the building were considered together. In practice there is usually little correlation. Even if the lanterns are of handsome design, their effect is spoiled by neglect in the method of installing the illuminant.

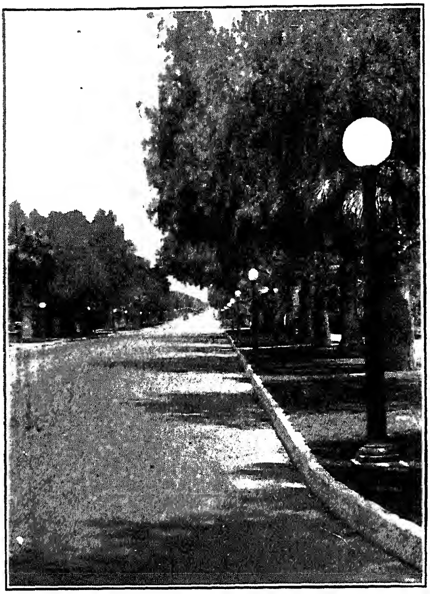


Fig. 188.—Ornamental lamp-posts with white glass (Alba) globes, as used in some American parks.

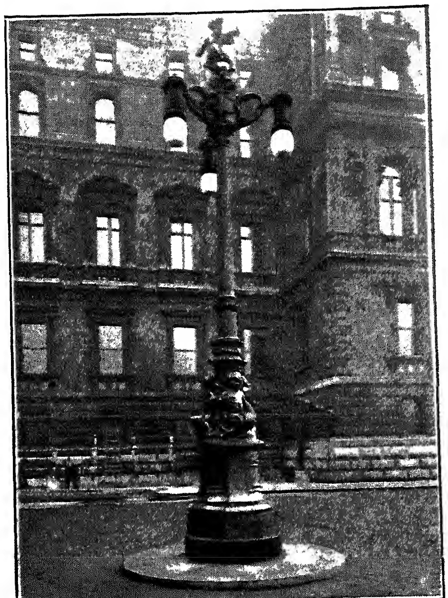
Similar considerations apply to the lighting of important squares and large outside areas. The appearance by night of such areas as Trafalgar Square in London or the Place de la Concorde in Paris depends much on the artificial lighting. The present heterogeneous collection of lamps is not happy. Dr Bell has pointed out that a multiplicity of small lights is usually not desirable in such cases, and speaks with approval of the plan adopted at the Potsdamerplatz in Berlin, which is illuminated by a series of flame arcs placed on high masts of special ornamental design.

Another special problem in outdoor illumination is the illumination of parks. As places of recreation which might well be more widely used during the summer (even in the uncertain weather of London), parks should be lighted on a more generous scale than at present. A moderate general

Arc lamp standard (near Cockspur Street).

High-pressure gas (Victoria Street).

Special bronze design.
(Buckingham Palace and the Mall.)



Special standard (awarded prize in Royal Academy competition) (Horse Guards' Parade).

FIG. 189.—Some London lamp-posts.

illumination would often be of service to the police in dealing with disorderliness; in the case of large wooded areas general illumination would hardly be feasible at present, but the main pathways should be illuminated. In some of the London parks, the present arrangements in this respect add considerably to the utility of the paths in the night-time. In the United States the use of tungsten lamps in white diffusing glass globes on ornamental standards has been effectively employed, and seems very suitable for the purpose. We shall have something to say

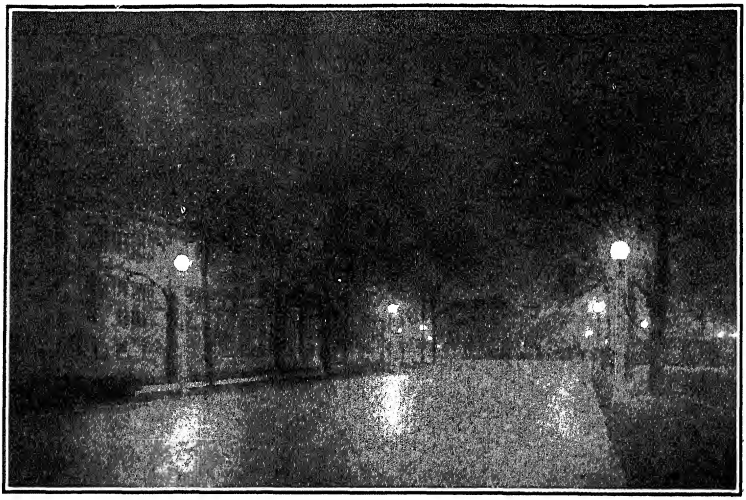


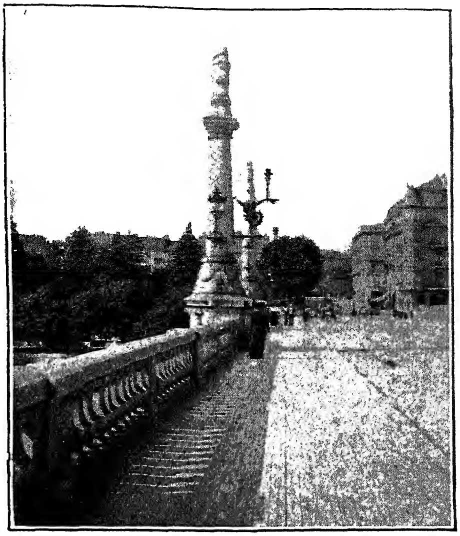
FIG. 190.—Tungsten lamps in Alba globes on columns. (Entrance to Lincoln Park, Chicago, U.S.A.)

later regarding the special decorative lighting of parks and exhibition grounds on festive occasions.

Yet another special problem is the arrangement of lights on bridges. In many cases the volume of the traffic certainly justifies good lighting. A point worth notice is the distribution of the illumination from lamps lining the balustrades. These lamps are not infrequently installed without any special form of directing globe, so that quite half the light produced is thrown outwards over the water. One would suppose that a preferable plan would be to obscure partially the side of the globes facing the river. The spreading out of the light in this way would doubtless make the lights more effective seen from a distance, and the increase in the amount of light reflected towards the centre

of the bridge would be of value. In all such cases the decorative side of illumination is worth a thought. On one of the bridges in Berlin a very pleasing arrangement is the erection of a series of statues, each of which carries a lamp equipped with a diffusing globe. Through the courtesy of Dr Louis Bell this is shown in fig. 191, *b*.

The value attached to the decorative and artistic side of public lighting will naturally depend on the importance of the locality. One would imagine, for example, that in the



(*a*) Pont du Couloureniére, Geneva.

(*b*) Augustus Brücke, Berlin.

FIG. 191.—Ornamental lighting on two Continental bridges.

case of roads or broad paths in parks leading to a royal palace some specially fine design might be adopted in order to intimate to strangers the fact of his approaching a king's residence.

There are also many instances in which an extra illumination in the streets is required for the benefit of certain private consumers, for example, in the form of parade lighting outside shops in order to attract attention. Of recent years the Gas Companies have made a feature of this form of advertisement, high-pressure lamps being installed outside shops and supplied with gas for an inclusive charge per annum. In the United States the method has also been widely used, and experiments

have been made with a view to demonstrating the increase in traffic arising from improved illumination in business thoroughfares. It may be noted, however, that a great increase in the illumination for the pavement necessitates a corresponding increase in the lighting of the window in order that the goods may "stand out" satisfactorily.

Extra lighting of this kind may add considerably to the general illumination in a street. The same applies to lamps hung outside shops and places of entertainment, and in a measure to the light reflected from the goods in show-windows. Illumination derived from these sources may be very useful, since by this means we approach nearer to the conditions met with in interior lighting: the light comes from many different directions and dense shadows are to some extent avoided. A street lined with well-lighted shops naturally gives the impression of being better illuminated than one lined by blank walls.

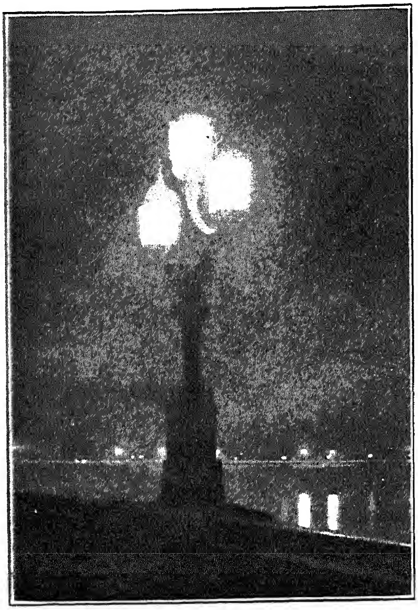


FIG. 192.—Night view of standard carrying incandescent electric lamps, on Westminster Bridge. In the distance the lights of the Embankment.

On the other hand, private lighting of this kind needs to be thoroughly supervised. There is no hardship in asking that brilliant lights outside shops should be screened on the side facing the street. The mere multiplication of bright lamps outside a building can hardly be described as the most effective form of advertisement. When the electric arc and high-pressure gas lamp were new, something might have been said for their use in this way, but at present such lamps are quite familiar objects. It would surely be better to make use of novel colour devices, illuminated signs, etc., in order to attract attention, than to rely on mere brilliancy.

FIG. 193.—"Parade" gas lighting on the Lewisham High Road, London. An example of strong local illumination for shopkeepers.

FIG. 194.—Very powerful pavement lighting by 10-amp. Excello arc lamps, two on a post, only 16 feet above the ground and 50 to 75 feet apart.

Illuminated Signs.

This leads us to consider another section of outdoor lighting, namely, the use of illuminated signs. People are coming to recognise that a great deal of information can be usefully conveyed through *the eye* rather than through the ear, with the result that illuminated notices are much more widely used in our streets than they were a few years ago. The red lamp outside the doctor's house and the white letters on a blue ground outside the police stations have long been familiar. But the idea has spread. To-day, every up-to-date place of entertainment makes use of illuminated signs to indicate the name of the building and the nature of the amusement provided. The method might with advantage be applied in many other cases, for example, to indicate at once the whereabouts of a post office, museums, or important public buildings. A resident in the city naturally comes to know and recognise such buildings, but a stranger, who is not in this happy position, would often be grateful for some form of illuminated notice giving the desired information. Some people might think such signs out of place, but there is no reason why an illuminated device should not be a really pleasing and artistic object. Indeed, the use of light in this way offers scope for considerable artistic skill.

It may be of interest to summarise briefly the chief types of illuminated signs now available.

(1) *Signs outlined in Glow-lamps or Gas-jets.*—One of the most familiar types of illumination signs is that in which the letters are outlined by means of glow-lamps or small gas-jets. The use of gas in this way gives rise to a certain flickering effect which is not without value for spectacular purposes. For ordinary notices, however, the convenience of control and wiring has led to electricity being almost exclusively used.

During the last few years a marked improvement has taken place in these signs, owing to the introduction of the low-voltage metallic-filament lamp. It is obvious that there is a limit to the necessary brightness of lamps used for these purposes. In many cases quite as good an effect will be produced by a small-voltage lamp giving only 2 to 5 c.p. as would be given by a more powerful one, and the consumption of electricity is very much less.

The coming of the low-voltage metal-filament lamp has therefore given a great impetus to these signs. Lamps consuming

only a few watts each are commonly wired in series-parallel or run off a small transformer, and the small glittering points are now quite a feature in the west end of London. Another improvement has been the use of these miniature lamps with a white or coloured background, which softens any brilliancy and gives "body" to the letters. Such signs are readily switched on and off as required. By means of special motor contrivances it is possible to "flash" the lamps or to turn on and off certain groups of lamps in regular succession and thus produce moving pictures. For example, by this means one can imitate the movement of a snake or playing fountain, and moving pictures (divers, performing animals, figures throwing balls, etc.) have been imitated in a most ingenious manner.

Another variety of this type of sign utilises groups of lamps from which all the letters of the alphabet can be formed. By means of a motor carrying a special commutating device any number of separate sentences can be formed in succession, and it is possible to present a series of illuminated notices. Several signs of this kind have been put up in London, and Prof. Biscan has described the details of their mechanism.[1]

A drawback to signs consisting of a number of small lamps is that they are apt to get encrusted with dirt and are not very readily cleaned, and the fact of there being so many lamps to maintain and replace, and such a multiplicity of connections, is also something of a disadvantage. On the other hand, if properly supervised, they give some charming effects.

(2) *Transparency Signs using White Glass.*—A simpler and in some respects more advantageous form of illuminated sign is that in which the illuminant is placed behind a screen of translucent diffusing material such as opal glass, silk, etc., on which letters or designs are traced. The mild luminosity of the background enables these signs to be inspected at close quarters without any feeling of glare.

By merely altering the letters it is easy to change the character of the notice without altering the mechanism of the sign. This type of sign is therefore very useful for indicating a changing programme. They are also widely used on the underground railways to-day in order to give information to passengers regarding the destination of trains, etc.

Generally speaking, the consumption of gas or electricity required in lighting a sign of this kind will be less than in one

[1] *Elektrische Lichteffekte*, p. 86.

outlined in lamps in the manner described above, particularly in the case of small signs. Other advantages are that the lamps can be easily renewed, and the surface presented readily cleaned.

In shop windows so-called "reflecting signs" are becoming common. In this case the translucent surface carrying an appropriate notice or advertisement device is merely hung in front of the lamps so as to receive the rays and screen the filaments from the eyes of people looking into the window. The surface of the sign also serves to reflect some of the rays from the lamp back on the goods.

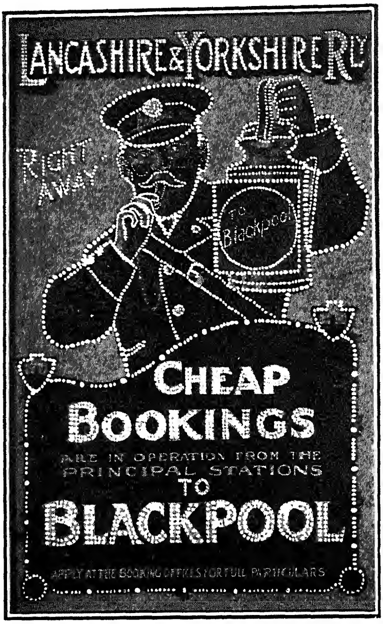


FIG. 195.—Bead (Venner) glass sign as used outside railway stations.

(3) *Bead Glass Signs.*—Signs of this kind are similar in principle to those described in the previous section, except that the opal glass or other uniform surface is replaced by a series of spherical glass beads. The effect of using such beads is that the letters or figures are traced out as a series of bright dots. In some cases beads of various sizes are used to indicate the title and the sub-heading, in somewhat the same way as a printer uses various sizes of type. The novelty of this type of sign has been an attraction, and if carefully designed it is capable of good effects. Care is necessary to secure an even illumination. In some cases, from mistaken economy, such signs are underlighted, with the result that their brilliancy varies according to the direction from which they are viewed. In this and the previous class of sign colour effects can be very easily produced by installing tinted lamps.

(4) *Signs illuminated from in Front.*—Finally there is the class of sign, not very widely used as yet, in which the illumination is provided by concealed lamps in front. It would appear that this should be one of the economical forms of signs. A surface brightness of 10 to 20 foot-candles, such as can be

readily produced by a white surface lighted by well-placed reflectors, is probably sufficient to enable a sign to be seen well at all ordinary distances. Moreover, the distribution of the light should be readily controllable by modern forms of reflectors, and the waste (owing to rays being wrongly directed and not striking the surface of the sign) reduced to a minimum.

In some cases (*e.g.* some of the notices of routes outside underground railways) parabolic steel reflectors have been used with electric lamps for this purpose. Reflectors of similar shape

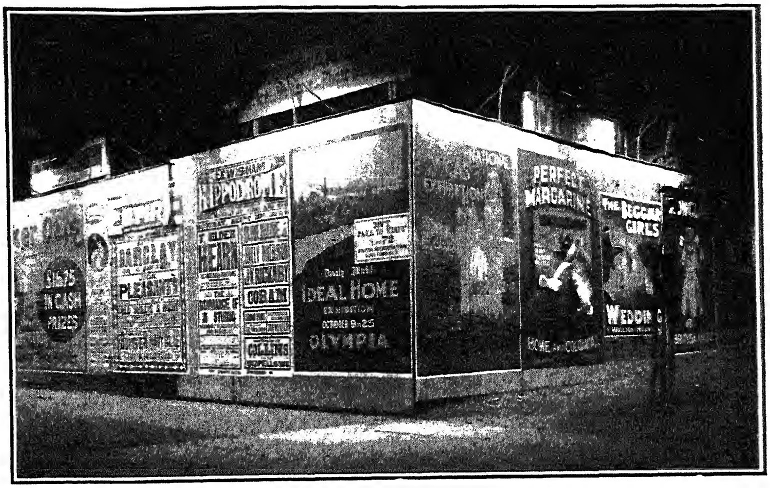


FIG. 196.—A series of posters in the district of the South Metropolitan Gas Co., London, illuminated by gas lamps with special opaque reflectors, distributing the illumination evenly over the surface.

have also been used with gas lamps or arc lamps to illuminate signs of a considerably large area, advertisement posters, etc. Another new method of dealing with the problem is by the use of tubular lamps and a specially designed strip reflector, of which the Holophane Uniflux reflector may be mentioned as an example. By a reflector of this kind, specially designed to produce even illumination, a given brightness should be produced very economically. The method has recently been adopted for illuminating the large gold letter sign at Mme. Tussaud's (Baker Street, London). An advantage of this type of sign is that the wiring and piping of the lamps are not in any way different from that met with in ordinary illuminating engineering; and the fact of the illuminants being entirely separate from the

illuminated surface, enables the latter to be very readily changed or cleaned. On the other hand, it must be remembered that it is naturally not as a rule possible to get the same degree of contrast from this type of sign as from a transparency; we have here the same fundamental distinction as exists between a photographic print and a lantern slide.

There is another form of sign (Meteor) that has quite lately been introduced, and which consists of a plate of glass illuminated by concealed lamps above and below. The rays of light entering the glass are kept entirely within it by total internal reflection, and any letters stencilled on the back appear brightly illuminated without the actual source of light being seen.

It is difficult to set a limit to the utility of illuminated signs. Information can so readily be conveyed simultaneously to a large number of people by this means; we have already remarked on the services they are rendering on the railways by saving needless questions on the part of passengers.

Already tramcars and 'buses are making use of illuminated destination placards, a very obvious necessity with modern traffic by night-time. At present we have not quite got to the length of illuminating the names of streets; but it seems reasonable to suppose that it will not be long before this is done in the main thoroughfares.

Outside places of entertainment signs already form quite a conspicuous feature, a special recent development being the "picture-sign"—often a decidedly artistic production. It is worth noting that the artist has not yet explored to any great extent the possibilities of the transparency in art; one would suppose that the infinitely greater range of contrast available when pictures are illuminated from behind would enable him to get effects that it would be impossible to reproduce on canvas in the ordinary way.

Vehicle Lighting.

The lighting of vehicles has also undergone a remarkable change during recent years. Originally the only function of lights fixed on carriages was to enable their presence to be recognised by other vehicles. They were not intended to illuminate the roadway to any extent and doubtless served their purpose in the days of slow horse-driven traffic.

In practically all the civilised countries regulations are in force prescribing that vehicles should carry such lights in the

dark, and it has even been suggested that drivers of cattle, etc., on the highways by night should carry a light to indicate their presence.

The introduction of motor traffic has brought about a complete revolution in the lighting of vehicles. A car travelling at a high speed requires lights, not only to indicate its presence to other drivers, but to illuminate the roadway as well. The driver must be able to see his route a considerable distance ahead; he needs to distinguish small obstacles, such as might cause little trouble to slow traffic but would be dangerous to a car travelling at a high speed.

A great deal of ingenuity has recently been expended on the design of such headlights; at the various motor exhibitions, lighting now forms a section in itself. There has been much discussion on the merits of acetylene and electric lighting. The cleanness of the latter and the ease with which it can be controlled are advantages. On the other hand, the electric filament, not being a "point source," is not quite so suitable optically for use with a parabolic mirror as the continuous luminous area of an acetylene flame. The coming of the small-voltage metallic-filament lamps, and particularly those wound in a compact helix and composed of ductile tungsten, has proved a distinct gain. Electric lighting has also been helped by the design of ingenious forms of dynamos giving practically a constant current independent of the speed. This has been largely instrumental in removing the difficulties attending the maintenance of a battery of accumulators. Similarly the introduction of tubes of dissolved acetylene has made the use of that illuminant decidedly more convenient.

A number of papers have recently appeared discussing the design of electric headlights for motor cars and locomotives.[1] On the railway the nature of the headlights used on express trains is an important matter; the gain in increased illuminating power is valuable to the driver in enabling him to recognise any obstacle on the line a long way ahead. On the other hand, the glare from a very powerful headlight may dazzle the eyes of the driver of an approaching train and might lead to his mistaking a signal.

A somewhat similar problem is encountered in connection with headlights for automobiles. The driver requires a powerful light to show up the road, but it seems to be no easy matter

[1] "Headlight Tests," by C. M. Larson, *Elect. Ry. Journal*, 23rd Nov. 1912.

to satisfy him in this respect and yet to avoid dazzling the approaching pedestrian. On the other hand, it has been suggested that the fan of light should be entirely confined below the level of the pedestrian's eyes, so as to illuminate the roadway and surroundings to some extent but not to be readily visible to his eyes. Some discussion on these and similar points followed a paper read before the Illuminating Engineering Society (London) by Dr H. R. B. Hickman in 1910.

The photometry of headlights of this kind presents considerable difficulties. A series of tests was carried out by the Royal Automobile Club in 1909. There is little doubt that some of the conventional methods of estimating the candle-power of searchlights are somewhat loose, and that general agreement on some precise method might be useful to those responsible for lighthouses, beacons, and coast lighting generally.

The illumination of railway signals is, again, a subject on which there is much dispute, and there seems to be a need for more definite understanding as to the intensity of the lights required for various purposes. Reference was made in Chapter IV. to the use of flashing acetylene lights, as additional means of discrimination, besides colour. The changes that occur in the appearance of coloured lights in various atmospheric conditions and as the distance of the observer changes have also been commented on, and it is possible that some mistakes have been caused in this way. There seems to be general agreement that ordinary blue glass is unsatisfactory. The explanation probably is that deep blue glass usually shows an absorption point in the centre of the spectrum, but transmits bands in the red and the blue. At close quarters the light is somewhat purple in tint; but when it is viewed from a distance the eye may be unable to bring the blue rays to a focus, with the result that the colour changes almost to red.

While the use of headlights on moving vehicles has developed, a great change in the standard of the inside lighting has also taken place. The application of electricity to traction naturally afforded means of lighting carriages with very little extra trouble. The result was that electric trams were lighted far more brilliantly inside than the old horse trams had been, and it is probable that in this country the electric underground railways have had a similar effect in raising the standard of carriage lighting.

Again, when electric lighting began to be used for motor-car headlights, the convenience of this method of lighting for the

interior of the cars was also appreciated; a large modern motor car has frequently quite an elaborate switch-board controlling the complete lighting of the car.

Many readers of this book will recall the exceedingly dim illumination from smoky lamps which were characteristic of most railway carriages and omnibuses twenty or thirty years ago.

At the present time the standard of comfort in travelling has risen very greatly. People expect to be able to read in comfort,

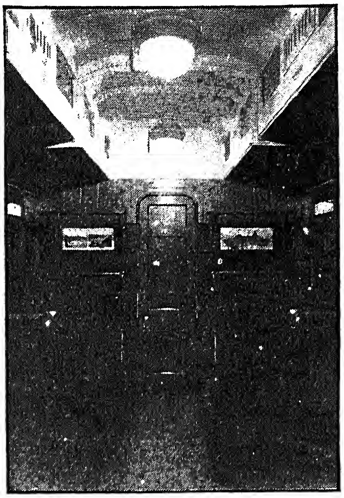


FIG. 197.—Gas-lighted saloon (G. W. Ry., England), with central lamps in ceiling recess.

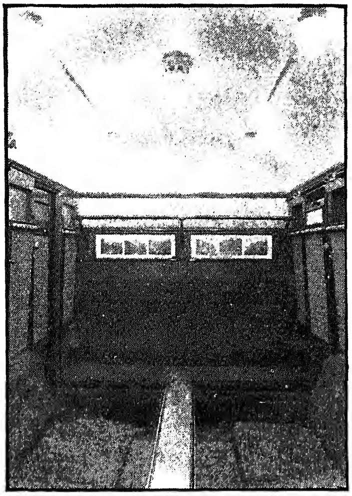


FIG. 198.—Electrically lighted saloon (G. W. Ry., England), lighted by tungsten lamps in etched glass globe.

and in many cases would prefer a route which enables them to do so even if this involves a slightly longer journey.

We do not wish to enter into the vexed question of conditions by gas and electricity for train lighting. Many factors enter into this problem besides that of cost—factors which are not always considered in such discussion.

Modern methods enable quite a good illumination to be obtained by both systems of lighting, but it is probable that in both cases more might be done than has yet been accomplished in the way of using the light produced for the comfort of passengers. The existing systems of carriage lighting may be divided roughly into two groups. In a carriage divided into compartments it is usual to put one or two lights exactly over

the gangway. This is perhaps the most convenient method from the standpoint of the company, and in many cases may give rise to fairly good results, particularly if the upper part of the carriage is light in tint and reflects the rays downwards. Nevertheless a light in this position faces the people seated on both sides of the carriages and is by no means conveniently placed for reading. A slight tilting of the book or paper will mean that the direct rays fall on the page obliquely; and directly the reader raises his eyes he catches sight of the light overhead. A preferable method from this standpoint is undoubtedly to fix the lamps on the partitions on either side of the carriage so that the rays can fall over the people's shoulders. The lamps should of course be screened by appropriate shades.

In the case of carriages without compartments, there is commonly a row of lights down the middle. The movement of the train makes it impossible to use pendant fixtures, and shading devices should be fixed rigidly, a favourite and apparently serviceable method being to mount diffusing glass hemispheres straight on the celling. It would appear, however, that in some of the American trains indirect lighting is now being introduced.

In tramcars one usually finds two rows of lights down the sides of the carriage. At present there is rarely any very serious attempt to screen these lamps from the eyes. Consequently the row of bare metal filaments is apt to be decidedly trying, especially in view of the flickering of the light caused by the lamps being run straight from the traction voltage. It is sometimes argued that shades are unsuitable in this case, as they would be apt to be broken by the "strap-hanger." But it is probable that a little ingenuity would overcome this difficulty. Several recent papers on the subject in the United States emphasise the value of a light finish for carriages and the desirability of employing reflectors to direct the rays of light downwards and screen the filaments.[1]

The following table is interesting in this connection:—

---

[1] "The Illumination of Street Railway Cars," by L. C. Porter and V. L. Staley (paper read at the Convention of the Illum. Eng. Soc., U.S.A., Nov. 1913). See also S. G. Hibben and E. M. Smith, *Elect. Journal*, June 1913, and J. L. Minick, "Illumination of Passenger Cars," *Trans. Am. Illum. Eng. Soc.*, May 1913.

STREET RAILWAY LIGHTING.

Illumination Data—Bare *versus* Shaded Tungsten Lamps.
(Hibben, *Trans. Am. I. E. S.*, 1913.)

	Bare Tungsten Lamps.	Shaded Tungsten Lamps.
Number of lamps	8·0	3·0
Candle-power per lamp	30·0	75·0
Watts per lamp	3·90	84·3
Total watts	312·0	253·0
Total generated lumens	2560·0	2142·0
Area car floor	194·0	194·0
Watts per square foot	1·62	1·31
Average foot-candles	2·71	3·24
Useful lumens	525·0	628·0
Utilisation factor	22·08%	29·30%
Relative efficiency	75%	100%

On the District Railway in London experiments are now being made with central ceiling lamps in diffusing glass hemispheres, which give a much softer effect than the rows of bare filaments which have hitherto been usual.

For further data on the lighting of railway carriages, 'buses, etc., in England, readers may be referred to a discussion opened by Mr E. Kilburn Scott before the Illuminating Engineering Society (London) in 1914.[1]

RAILWAY STATION LIGHTING.

The lighting of railway platforms, booking-halls, offices, goods yards, etc., also present points of interest, and was discussed in a paper read by Mr Haydn T. Harrison before the Illuminating Engineering Society in London in 1912. The lighting of railway platforms would seem to be approaching standardisation. From a number of tests presented at the meeting referred to, it appeared that the minimum illumination on most main station platforms is about 0·25 foot-candle, a figure which is also about the minimum encountered on the tube railways of London. In the tubes the reflection from the white tiles simplifies the problem and makes platform lighting a much easier matter than in the case of large stations above ground, having only a very distant glass roof. From the standpoint of passengers, an even illumination all over the platform would seem desirable, and it seems immaterial whether this is

[1] *Illum. Eng.*, London, May 1914.

obtained by small units placed near together or by more powerful lamps hung high up. But it is objectionable to be able to see a long row of bright points, and we find that in platform lighting it is now becoming usual for the lights to be well shaded, so that the mantle or filament cannot be seen from a distance. Much of the lighting on the London underground railways is excellent in this respect.

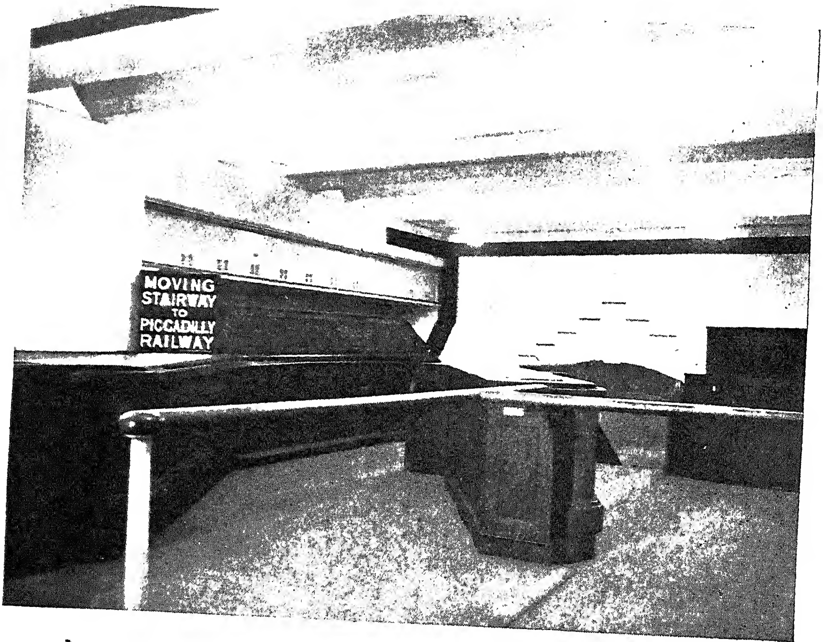


FIG. 199.—Entrance to "escalator," Earl's Court, London, showing semi-indirect lighting and illuminated direction sign.

It is interesting to observe that when the City and South London tube was opened about 1890 the illumination was probably only about one-twentieth of that provided on many of the platforms to-day. Yet the newspapers of that time all commented on the brilliant lighting, which was considered something far in advance of anything that had prevailed before. In passing it may be remarked that the simple device of drawing a white line down the edge of the platform where the trains come in helps materially to show where the platform ceases; when the platform and the rail-bed have approximately the same tone they are apt to be indistinguishable in a weak illumination.

There are also opportunities for effective lighting in the booking-halls, passages, and restaurants at a main railway station. In the booking-hall, besides a fairly cheerful general illumination of, say, 1 foot-candle or more, there should be local illumination at the grille where tickets are purchased. In many stations a local shaded lamp, also illuminating a sign-transparency bearing the words "booking-office," is conveniently

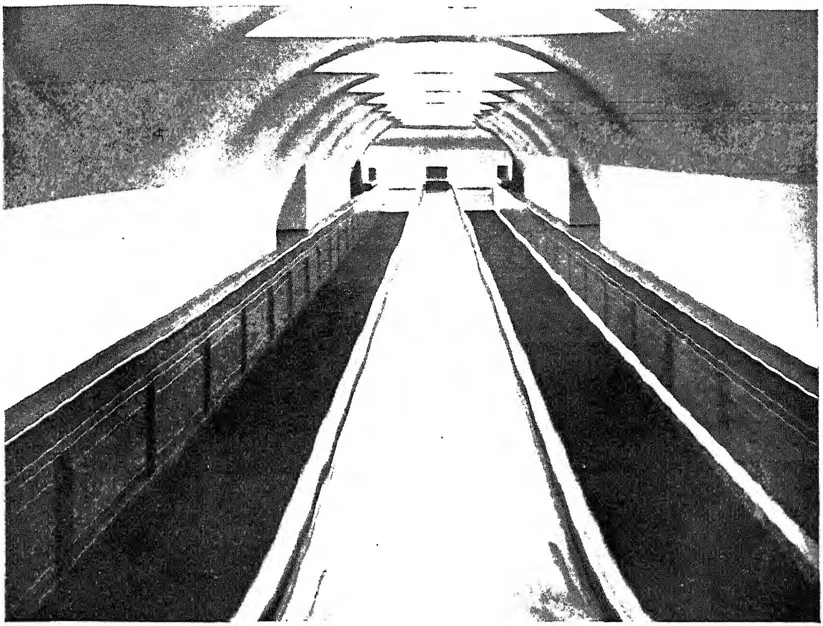


FIG. 200.—View looking up escalator, Earl's Court, London, showing method of lighting by lamps concealed above glass panel in the ceiling.

used. Reference has already been made to the great value of the illuminated notices indicating the arrival, departure, and destination of trains. Some of the main termini have now quite elaborate tables of this kind, which are undoubtedly a great help to passengers. As yet we are waiting for the illuminated time-table, but no doubt it will come in course of time. Another novelty which will surely become general before long, is the lighting up of the names of stations at night. Some illumination is really necessary, especially at the less important stations where the general lighting is not very strong. The method of lighting should also be distinc-

tive so that the names stand out clearly from the ubiquitous advertisement.

On the tube railways the high general illumination in the stations makes local lighting for the names less vital, but on some of the platforms it has nevertheless already been introduced. In other directions the tubes have likewise shown commendable enterprise, for example, in the matter of corridor lighting. Various methods have been contrived to avoid the glare from a succession of bright lights, one of the most complete being the screening of lamps in channels specially cut in the ceiling for the purpose. The lighting of the escalator (moving staircase) also presents a special problem, as it is desirable to avoid dazzling the passenger and inclining him to stumble. At the Earl's Court (London) escalator the lamps are concealed above diffusing glass plates in the roof, the latter being sloped in such a way as to be invisible to passengers coming down the staircase (who are considered more likely to stumble than those coming up). At the similar moving staircase at Liverpool Street station, the illumination is at present provided by a Moore tube running the entire length of the steps and giving a soft and even light.

The railways are also quick to appreciate the value of the illuminated sign as an advertisement, and now habitually make use of views, lighted up from behind, of celebrated scenery on their route.

Ship Lighting.

The lighting of ships has a certain amount in common with the illumination of underground railways. Many parts of the interior of a ship can only be seen by artificial light; the access of daylight being practically nil. It is therefore obvious that good artificial lighting is important; yet both on warships and on merchant vessels the conditions of illumination below deck are often very primitive. At the Annual Congress of the Royal Institute of Public Health held in Paris in May 1913, Fleet Surgeon W. N. Whitelegge mentioned "constant living below deck under artificial light, the inconvenient situation of lamps, and the want of proper shades" as among the causes of eye-strain in the navy. The special limitations of lighting on board ship imposed by the facts that there is no external source of gas or electricity, that pendant fixtures cannot be used, the low ceilings, etc., are sometimes mentioned as excuses for

ignoring the simple precautions observed on land. But there seems no reason why such difficulties should not be overcome. and it is highly probable that the health and spirits of seamen suffer when they are cooped up in cramped and badly lighted quarters.

On a modern liner, with its elaborate catering for the wealthy passenger, there is ample scope for the skill of the lighting engineer; in fact, he meets most of the problems likely to crop up in a large hotel or club on land.

Another point that has been clearly demonstrated in several recent mishaps at sea, is the value of "emergency lighting." On a sinking ship the failure of the electricity supply may bring about something approaching a panic. The confusion is naturally accentuated by the darkness, and the efforts of the officers and crew are impeded. If portable outfits of dissolved acetylene or other appropriate system of emergency lighting were stored on deck, they might often render good service in the event of a disaster.

We may briefly mention several other possibilities of outdoor lighting. It has been shown that light plays a great part in evening entertainments and spectacles, and the lighting of quite large arenas has sometimes been quite successfully accomplished. When we are dealing with large outdoor areas we are faced by the alternative of arranging the lamps on masts, as in street lighting, or suspending them on wires having a considerable span. This seems to limit the use of artificial light to enable outdoor games to be played by night. There is no insuperable difficulty in illuminating an outdoor lawn-tennis court or golf putting-green sufficiently brightly. But when we come to such large areas as football grounds, golf greens, etc., the task is more difficult. A ground on which drilling takes place, or races are run, might be illuminated artificially, even though the expenditure of gas or electricity might be considerable. For in such cases posts at intervals could probably be used, and the movements of performers controlled in such a way as to steer clear of the obstructions. But on a football ground or hockey field, where players run about in all directions, posts would clearly be inadmissible. The only solution would appear to be lamps suspended above the field on wires stretched right across. Now that such very large "gates" are obtained at professional football matches, the possibility of playing off

matches by night will probably be considered. Indeed, in a few cases the experiment has been tried, but apparently not with very great success.

Outdoor Decorative Lighting.

The two chief occasions on which we witness a deliberate attempt to use artificial light out-of-doors as a decoration are, firstly, at exhibitions, secondly, when the streets are illuminated on festive occasions, or during times of national rejoicing. As a rule such decorations are put up at short notice and on a stereotyped principle. The method almost invariably employed is to use festoons of coloured incandescent lamps, or to outline

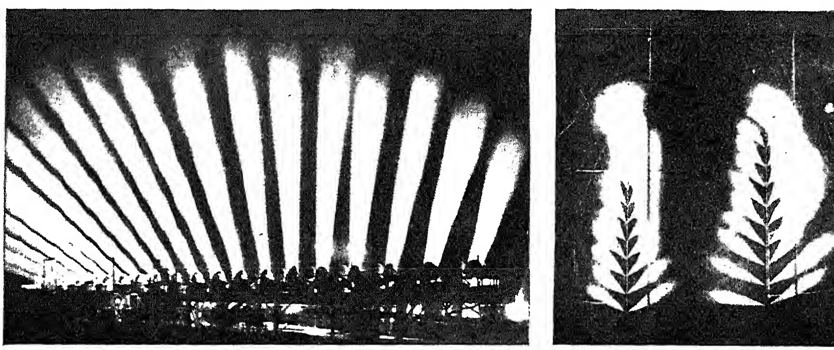


Fig. 201.—A novel spectacular device used in the United States. Jets and clouds of steam illuminated by coloured searchlight beams.

the shapes of buildings with them. At the last great display in London on Coronation night, the volume of light was greater than on any previous occasion; but it was commonly remarked that the methods showed little advance over those of the past.

At the present moment it is difficult to foresee the future trend of spectacular and decorative outdoor lighting. In figs. 201, 202 we give examples of some novel American devices of a spectacular kind. It seems probable that ultimately the "artist in light" will rely on illumination by means of concealed lights of the frontages of buildings, and on the cunning combination of artistic illuminated lanterns and devices with these background effects, rather than on the multiplication of bright points of light. At exhibitions such as the White City, where buildings having a light exterior are available, such methods should meet with success. Another method which is now being

developed in the United States is the illumination of monuments and buildings by searchlight beams—a device which can be abused but also seems to have artistic possibilities. It is rumoured that at the great exhibition now being organised in San Francisco some very novel decorative effects will be seen.

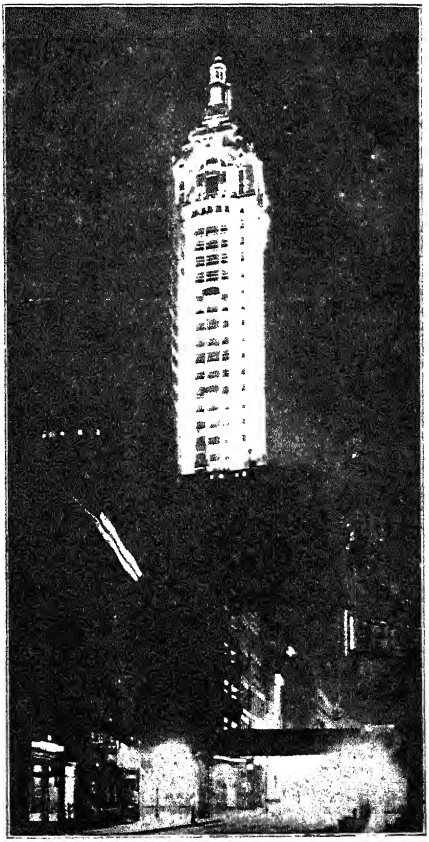


FIG. 202.—The Singer Tower (the tallest building in New York) illuminated by concealed searchlights, so as to stand out from the surroundings.

There is one principle in public lighting which we think will be generally accepted, namely, that if the artistic aspects of public lighting are to be developed, they should be worked out on some coherent scheme, and should be so supervised as not to be prejudiced by unchecked private enterprise. At the time of the Coronation decorations, it was remarked that the lack of

FIG. 203.—Cluster of flame arcs with coloured globes, mounted on post of Gothic design, at the Boston Electric Show, 1912.

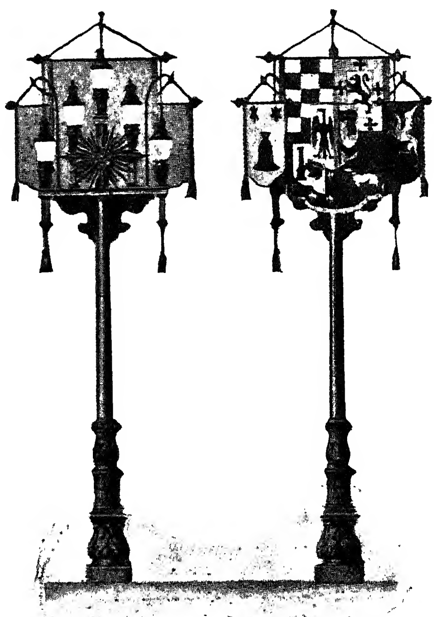


FIG. 204.—Banners bearing coloured devices illuminated by concealed flame arcs, designed for use at the San Francisco Exhibition.

any definite scheme was a defect. Many exhibitions, good in themselves, were unsatisfactory because they clashed with a neighbouring display. Clearly it would be better if the lighting of each street were schemed out as a whole.

We must now bring this work to an end. Doubtless much that has been written will require revision in the course of a few years. It may appear to some that we have dealt with the subject of illumination in a somewhat general and discursive manner, and have omitted many details that the expert would like to know. But in the case of a new subject such as this, ideas are in a constant state of flux. Some principles of illumination can now be clearly stated: but the practice of illuminating engineering is changing every day. For this reason we have been content to cast an eye over the subject as a whole, rather than to occupy ourselves with details.

But in any case the subject is now so vast that a special text-book is needed to treat any section of lighting thoroughly. It is probable that quite a number of such specialised works will now begin to make their appearance, and there are many subjects on which they would be welcome.

Since the above words were written the peace of Europe has been suddenly shattered, and its nations are engaged in the most desperate struggle the world has ever seen.

A new chapter in illuminating engineering might be written on the utilisation of light in warfare. It is sad to think that light, so long regarded as a civilising influence, should now be applied for purposes of destruction. But if light is used to destroy life, it is also being employed, in the field hospitals and as an aid to the search for wounded on the battlefield, as a means of preserving it.

When this war is ended a striking account of the use of light in military operations might be written. Meantime, we can only hope that the termination of this terrible struggle will ensure peace for future generations, and that in time to come the many international ties which it has severed will be drawn closer than ever before.

APPENDIX.

LIST OF WORKS DEALING WITH ILLUMINATION.

THE following list is not intended to be exhaustive, but contains most of the books on illumination published from 1905 up to the end of 1913. We have also included a number of books published previous to this date which are likely to be of interest. This list should be regarded as supplemental to the references occurring in the text.

Those books indicated by an asterisk (*) are also remarkable for the number of references contained, and articles on illumination and photometry.

For the sake of convenience, the journals dealing mainly with gas or electric lighting, etc., have been numbered under this heading; but it should be remembered that many of these journals frequently contain articles dealing with general illumination.

The number of journals that contain occasional articles on lighting is very large; all that has been attempted is to collect a few of those which deal most constantly with the subject.

ILLUMINATION AND PHOTOMETRY.

BOOKS.

ABNEY, Sir WM. DE W., *Colour Vision* (Sampson Low & Co., London, 1895: pp. 231).

—— —— *Researches on Colour Vision* (Longmans, Green & Co., London, 1913: pp. 418).

ALLEMAGNE, *Histoire du Luminaire* (Alphonse Picard, Paris, 1891).

ALLEN, GRANT, *The Colour Sense, its Origin and Development* (Trübner & Co., London, 1879: pp. 282).

BELL, L., *The Art of Illumination* (McGraw-Hill Co., New York and London, 1912: pp. 353).

BERTELSMANN, W., *Rechentafeln für Beleuchtungstechniker* (Ferd. Enke, Stuttgart, 1910: pp. 95).

BLOCH, L.,* *Grundzüge der Beleuchtungstechnik* (Julius Springer, Berlin, 1907).

—— —— *The Science of Illumination* (translation of the above book by W. C. Clinton: John Murray, London, 1912: pp. 180).

BLOK, A., *Elementary Principles of Illumination and Artificial Lighting* (Scott, Greenwood & Son, London, 1914: pp. 234).

BRÜSCH, W., *Die Beleuchtungsarten der Gegenwart* (B. G. Teubner, Leipsic, 1906: pp. 164).

BUTTNER, M., *Die Beleuchtung von Eisenbahnwagen* (Julius Springer, Berlin 1912: pp. 235).

CLEAVES, M. A.,* *Light Energy* (Rebman, New York and London, 1904: pp. 827).

CLEWELL, C. E., *Factory Lighting* (McGraw-Hill Book Co., London and New York, 1913: pp. 161).

CRAVATH, J. R., and LANSINGH, V. R., *Practical Illumination* (McGraw Publishing Co., New York, 1907: pp. 356).

DEFRANCE, *Histoire de l'Éclairage des Rues de Paris* (Imprimerie Nationale, Paris, 1904: pp. 125).

DIBDIN, W. J., *Public Lighting by Gas and Electricity* (The Sanitary Publishing Co., London, 1902: pp. 536).

ECK, J., *Practical Illumination* (S. Rentell & Co., 1914: pp. 85).

EDRIDGE-GREEN, F. W., *Colour Blindness and Colour Perception* (Kegan Paul, Trench, Trübner & Co., London, 1909: pp. 322).

EHRIG, G., *Licht und Beleuchtung* (W. Engelmann, Leipsic, 1913: pp. 98).

GALLINE, L., and SAINT-PAUL, B., *Éclairage (Huile, Alcool, Gaz, Électricité, Photométrie)* (Ch. Dunod, Paris, 1904: pp. 697).

HÖGNER, P., *Light, Radiation, and Illumination* (translated by J. Eck: "Electrician" Publishing Co., London, 1913: pp. 88).

HORSTMAN, H. C., and TOUSLEY, V. H., *Modern Illumination in Theory and Practice* (American Book Supply Co., London, 1912: pp. 273).

HOUSTOUN, R. H.,* *Studies in Light Production* ("Electrician" Series, London, 1912: pp. 115).

HUNTER, J., *On the Influence of Artificial Light in Causing Impaired Vision and Methods of Preventing or Lessening its Action on the Eye* (Longman, Orme & Co., London, 1840).

HYDE, E. P., *Abstract Bulletin of the Physical Laboratory of the National Electric Lamp Association*, Cleveland, U.S.A., 1913: pp. 127.

JOHNS HOPKINS UNIVERSITY* (Baltimore, U.S.A.), Series of Lectures on Illuminating Engineering delivered Oct.–Nov. 1910; published by the University Press in two volumes, pp. 1054.

LIEBENTHAL, Dr E.,* *Praktische Photometrie* (Fr. Vieweg & Son, Brunswick, 1907: pp. 445).

MARÉCHAL, H., *L'Éclairage à Paris* (Librairie Polytechnique Baudry, Paris, 1894: pp. 496).

PALAZ, A.,* *Traité de Photometrie industrielle* (Geo. Carré, Paris, 1892; translated by G. W. and M. R. Patterson—Sampson Low, Marston & Co., London, 1894: pp. 322).

MONTFAUCON, DOM BERNARD DE, *L'Antiquité expliquée et représentée en figures* vol. mdccxix, Paris, 1719).

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ROBSON, P. A., *School Planning* (Nicholson-Smith, London, 1911 : pp. 54).
SHAW, E. R., *School Hygiene* (Macmillan & Co., London, 1911 : pp. 260).
STEINMETZ, C. P., *Radiation, Light, and Illumination* (McGraw-Hill Publishing Co., New York and London, 1909 : pp. 305).
STINE, W. M.,* *Photometric Measurements* (Macmillan, London, 1910 : pp. 270).
THOMPSON, SILVANUS P., *Light, Visible and Invisible* (Macmillan & Co., London, 1911 : pp. 292).
TSCHERNING. *Optique Physiologique* (Carré et Naud, Paris, 1898 : pp. 335).
UPPENBORN, F.,* *Lehrbuch der Photometrie* (edited by B. Monasch : R. Oldenbourg, Berlin and Munich, 1912 : pp. 420).
VON BENESCH, *Das Beleuchtungswesen vom Mittelalter bis zur Mitte des XIX. Jahrhunderts aus Oesterreich-Ungarn* (A. Schroll & Co., Vienna, 1909).
WEDDING, W., *Über die Wirkungsgrad und die praktische Beleuchtung der gebräuchlichsten Lichtquellen* (R. Oldenbourg, Munich, 1905 : pp. 94).
WICKENDEN, W. E., *Illumination and Photometry* (Hill Publishing Co., London, 1910 : pp. 195).

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The Lighting Journal (New York ; monthly).
Science et Art de l'Éclairage (Paris ; monthly).
Zeitschrift für Beleuchtungswesen (Berlin ; appears three times a month).
Licht und Lampe (Berlin ; fortnightly).

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BARHAM, G. B., *The Development of the Incandescent Electric Lamp* (Scott, Greenwood & Co., London, 1912 : pp. 200).
BARROWS, W. E., *Electrical Illuminating Engineering* (McGraw Publishing Co., New York, 1908 : pp. 216).
BERTHIER, A., *Les nouveaux Modes d'Éclairage electrique* (H. Dunod et E. Pinat, Paris, 1908 : pp. 270).
BISCAN, W., *Elektrische Lichteffekte* (Carl Scholtze, Leipsic, 1909 : pp. 184).
BLOCH, L., and ZAUDY, R., *Elektrotechnische Winke für Architekten* (Julius Springer, Berlin, 1911 : pp. 151).
BOHLE, H., *Electrical Photometry and Illumination* (Chas. Griffin & Co., London, 1912 : pp. 222).
BOHNENSTENGEL, E., *Konstruktionen Elektrischer Bogenlampen* (Fr. Enke, Stuttgart, 1909 : pp. 304).
CZUDNOCHOWSKI, W. B. VON,* *Das elektrische Bogenlicht* (S. Hirzel, Leipsic, 1906 : pp. 698).

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MATTHEWS, R. B., *Electricity for Everybody* (Elec. Press, Ltd., London, 1912 : pp. 313).

MONASCH, B.,* *Elektrische Beleuchtung* (Max Janecke, 1910 : pp. 333).

OGLEY, D. K., *Incandescent Electric Lamps and their Application* (Longmans, Green & Co., London, 1914 : pp. 107).

SOLOMON, M.,* *Electric Lamps* (Constable & Co., London, 1908 : pp. 321).

STOCKHAUSEN, K., *Der eingeschlossene Lichtbogen bei Gleichstrom* (J. A. Barth, Leipsic, 1907 : pp. 210).

TAYLOR, F. H., *Private House Electric Lighting* (Percival Marshall & Co., London, 1909 : pp. 142).

—— —— *How to use the Electric Light* (Percival Marshall & Co., London, 1909 : pp. 69).

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WEBER, H., *Die elektrische Kohlenfadenlampen ihre Herstellung und Prüfung* (Max Jänecke, Hanover, 1908 : pp. 260).

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Proceedings of the American Institution of Electrical Engineers (New York).
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Electrical World (New York).
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